A STUDY ON FLUCTUATION OF ZOOPLANKTON IN THE ESTUARINE WATERS AT COCHIN DURING MAY - SEPTEMBER 1991

DISSERTATION SUBMITTED BY

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IN PARTIAL FULFILMENT OF THE DEGREE OF

MASTER OF SCIENCE (MARICULTURE)

OF THE

COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY

भाकृअप
ICAR

POST-GRADUATE PROGRAMME IN MARICULTURE

CENTRAL MARINE FISHERIES RESEARCH INSTITUTE

(Indian Council of Agricultural Research)

COCHIN - 682 031

NOVEMBER 1991

C E R T I F I C A T E

This is to certify that this Dissertation is a bonafide record of the work done by **Kum. Maya Antony.T.** under my supervision and that no part thereof has been presented before for any other degree.

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C O N T E N T S

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PREFACE

This dissertation embodies quantitative aspects of zooplankton, their faunal composition and fluctuations in relation to the environmental characteristics of the Ernakulam channel in the Cochin backwater system extending between the Shipyard and Fairway buoy during the south-west monsoon season of 1991.

Zooplankton, being the secondary producers in the food-web of marine and estuarine ecosystems, are of considerable importance as food resource, either directly or indirectly, to the larval as well as the adult stages of several marine and estuarine organisms; while the early larval stages of most of these organisms constitute part of the zooplankton biomass and communities.

The Cochin backwater system is the largest of its kind in the south-west coast of India and is one of the most affected ecosystems in recent years by human interferences. Except for the shipping and other navigation channels, the backwater is considerably shallow having a mean depth of about 3.5 m. Due to the diurnal and seasonal changes in this estuarine environment, good part of the zooplankton communities tends to die within this ecosystem daily, sinks to the bottom and the dead plankters are added to the detritus. A part of the detritus thus accumulated, in turn, forms the food of some pelagic and benthic communities in the backwater; while a portion is transported to the neighbouring ecosystems by the influence of tides and fresh-water flow. The tides also play a vital role in the transport of live zooplankton to and from this backwater environment.

The environmental factors such as rainfall, temperature, salinity and dissolved oxygen have their role in the production and ecology of these planktonic organisms in this estuarine eco-system. The estimation of the space and time scales of variations in these planktonic communities may provide a soundest theoratical foundation for comparison with theory and also for practical predictions.

The main objectives of the present investigation are to obtain up-to-date information on (1) the quantitative aspects of the different zooplankton groups, (2) their fluctuation and relative abundance and (3) to study the influence of monsoon-related hydrographic parameters on the zooplankton groups during the south-west monsoon season. This comprehensive study was taken up since no work of such nature is available from this estuarine waterbody adjoining Cochin city since 1976.

The importance of zooplankton production, resume of relevant literature and scope of the study are given under the title '*INTRODUCTION*'. *The description of the environment, study* area, methodology, laboratory analysis and treatment of data are included in 'MATERIAL AND METHODS'.

The 'RESULTS' and 'DISCUSSION' of the dissertation embody sections relating to (1) the environment, (2) zooplankton composition, (3) their numerical estimation, (4) fluctuations, (5) relative abundance and (6) influence of environmental factors on zooplankton fluctuation. The salient features and findings of the present investigation are given in 'SUMMARY' followed by 'REFERENCES' which include the relevant literature cited in this dissertation.

I am greatly indebted to my Supervising Teacher, Shri G.S. Daniel Selvaraj, Scientist (SG), C.M.F.R.I., Cochin for his constant advice, inspiring guidance and whole hearted support throughout the course of this study and in preparation of the manuscript. I express my sincere thanks to Dr. P.S.B.R. James, Director, C.M.F.R.I., Cochin for all the facilities provided. I am thankful to Dr. K.S. Scariah, Semester-in-Charge for providing necessary facilities to carry out this work. I am much obliged to Dr. A. Noble, Principal Scientist for his valuable suggestions and encouragement. I wish to thank Smt. T.S. Naomi and Smt. M.P. Moly for helping in the identification of zooplankton groups. I express my gratitude to Shri T.V. Sathianandan, Scientist for the help rendered in the statistical analysis.

I record my gratitude to Shri A. Nandakumar, Shri C.N. Chandrasekharan, Shri M.J. John, Shri C.G. Thomas, Shri K.L.K. Kesavan and Shri V.A. Kuttappan for their timely help during the course of this investigation. My thanks are also due to Shri R. Anilkumar, Shri N.V. Thambi and the employees of R.V. <u>Cadalmin</u>-IX for helping in the collections.

I have taken the help and co-operation of my classmates, juniors and seniors especially, Kum. Sheeba Susan Mathews and Kum. Preetha Paul whose contributions I would like to acknowledge gratefully.

To the ICAR, I express my sincere thanks for providing the fellowship during the course of study.

I N T R O D U C T I O N

In a broad sense, plankton is considered as an index of fertility (Prasad, 1969), as the fishery resources of any aquatic system mainly depend on the magnitude of phytoplankton and zooplankton production. These, in turn, are influenced by various physical, chemical and biological factors. In the estuaries and backwaters, the zooplankton distribution varies considerably in space and time. Their fluctuations in relation to hydrographic parameters especially during the south-west monsoon play a vital role in the fertility of the estuarine ecosystem by the influx of nutrient-rich freshwater discharge from rivers and land drainage and by considerable admixture of nutrient-rich saline water by the tide and upwelling effect resulting in a highly complex environment.

The Cochin backwater is one of the major estuarine ecosystems in the west coast of India having permanent connection with the sea at Cochin and Azhikode and this facilitates free mixing of seawater with the freshwater discharge derived from the rivers and land drainage; and the regular tidal rhythm influences the mixing and flow pattern giving rise to the features of an estuary. Apart from tides, the seasonal outburst of monsoons, particularly the south-west monsoon has a great bearing on the environmental parameters like light penetration, temperature, salinity, dissolved oxygen, nutrients and in the species composition and succession of both primary and secondary producers. Such great changes in the environment, in turn, considerably influence the organic production of the ecosystem.

A perusal of literature on zooplankton from the estuaries revealed that the pioneering work on zooplankton in the estuaries of India was done by Sewell (1913) in Chilka Lake; while seasonal variations of plankton were studied by Menon (1945) from the Trivandrum coast; Dutta et al. (1954) from Hooghly estuary in relation to hydrography; Krishnamurthy (1961) from the Vellar estuary; Goswami and Singbal (1974) from the estuaries of Goa especially during the monsoon and Gajbhiye et al. (1984) from Versova creek (Bombay) on diurnal variations.

In the Cochin backwater, the pioneering work on plankton was made by George (1958) who enumerated the common groups and brought to light the relation existing between the seasonal changes of zooplankton population and some of the environmental factors. The other published informations relating to the distribution of zooplankton of Vembanad Lake and Cochin backwater in space and time (Nair and Tranter, 1971; Menon et al., 1971; Haridas et al., 1973; Silas and Pillai, 1975; Madhupratap, 1978; Madhupratap and Rao, 1979); and on the biology and distribution of specific groups such as copepods, chaetognaths, hydromedusae, siphonophores, decapod larvae and cladocerans (Wellershaus, 1969; 1970; Abraham, 1970; Pillai, 1970; 1972; Pillai et al., 1973;

Vijayalakshmi, 1971; Srinivasan, 1971; Santhakumari and Vannucci, 1971; Rengarajan, 1975; Mohammed and Rao, 1971; Pillai and Pillai, 1973; Madhupratap, 1979) revealed that their field investigations in the Cochin backwater were pertaining upto the year 1975 only.

The physico-chemical features of the Cochin backwater were studied by Balakrishnan (1957), Ramamirtham and Jayaraman (1963), Cherian (1967), Josanto (1971), Wellershaus (1973) and Sankaranarayanan et al. (1986). The diurnal observations on the physico-chemical features of the Cochin backwater were conducted in relation to tides by George and Kartha (1963), Qasim and Gopinath (1969) and Shynamma and Balakrishnan (1973).

The resume of literature indicates that little work has been done in the Cochin backwater on the zooplankton abundance and fluctuation coupled with environmental characteristics since 1976. It is to be noted that, in recent years, several changes have taken place in the ecosystem as a result of human interferences such as deforestation, reclamation, dredging operation and release of pollutants. The deforestation has not only resulted in heavy siltation and accretion of sand into the estuary which has affected the mean depth and tidal prism in the estuary, but also has impact on the irregularity in the seasonal rainfall. Other activities like release of pollutants from industries and over-use of pesticides and fertilizers in agriculture and subsequent land drainage during monsoon have serious impact on the ecosystem. Such man-made ecological changes stress the necessity for detailed investigation to assess the biological resources at all trophic levels in relation to the environmental characteristics of the ecosystem for up-dating the information on the potential resources.

While studying the seasonal fluctuation of zooplankton in the estuarine waters, what is needed is to estimate simultaneously the related environmental parameters from the same watermass prevailing in the same space and time, since these environmental factors show variations from place to place and time to time. Diurnal changes in the estuarine ecosystem also occur as a result of the water masses being constantly renewed by the inflow of freshwater from the rivers and seawater from the adjoining sea and by the local mixing processes.

Because of the importance of the backwater system as nursery ground for several cultivable species of fishes and shellfishes, and the role it plays in the general ecology as well as economy of the sea, this ecosystem has been the object of intensive studies by several workers of different fields. In recent years, the backwater is attracting greater attention as its vast stretches of the shallow water areas are brought under intensive culture of fishes, prawns and molluscs. The Ernakulam channel in the Cochin backwater forms the main source of estuarine waters to feed several hectares of potential aquaculture sites during high tide and to enrich the neighbouring marine environment during low tide.

The study of zooplankton can provide a basis not only for an understanding of variability, but also for the investigation of the relative importance of physical and biological factors in the control of pelagic ecosystem structure; and estimation of the space and time scales of this biological variance may provide a soundest theoratical foundation for comparison with theory and also for practical predictions.

In the light of the above facts, this dissertation presents the results of the investigations carried out in the Ernakulam channel of the Cochin backwater extending between the road-cum-railway bridge (in the south) and the Fairway buoy on the fluctuation and relative abundance of the dominant zooplankton groups in relation to the environmental parameters such as rain-fall, temperature, salinity, dissolved oxygen, tide and freshwater flow during the south-west monsoon season commencing from May to September 1991.

M A T E R I A L A N D M E T H O D S

Description of the backwater environment

The Cochin backwater system is an estuarine system and the largest of its kind in the south-west coast of India. It has an area of 300 sq. kms. extending from Alleppey in the south to Azhikode in the North between Lat. 09°32'-10°12'N and Long. 76°10'-76°29'E and having the Vembanad Lake in the south. It has got permanent sea connections at Cochin and Azhikode. This backwater system is subjected to strong tidal influence from the sea and mixing of freshwater from the river systems in the South and North, thus providing an estuarine condition with high salinity gradient towards the vicinity of barmouth. During the south-west monsoon season, almost freshwater condition persists throughout the estuary at the surface with saline condition at the bottom where depth is considerable. It is deeper in the harbour area reaching the maximum of 12 m and shallower in the upper reaches and along the sides with a depth range of 1-5 m. The southern sector of the backwater in the Cochin region is divided into 'Mattancheri channel' and the 'Ernakulam channel', separated by Willingdon Island.

Preliminary Survey

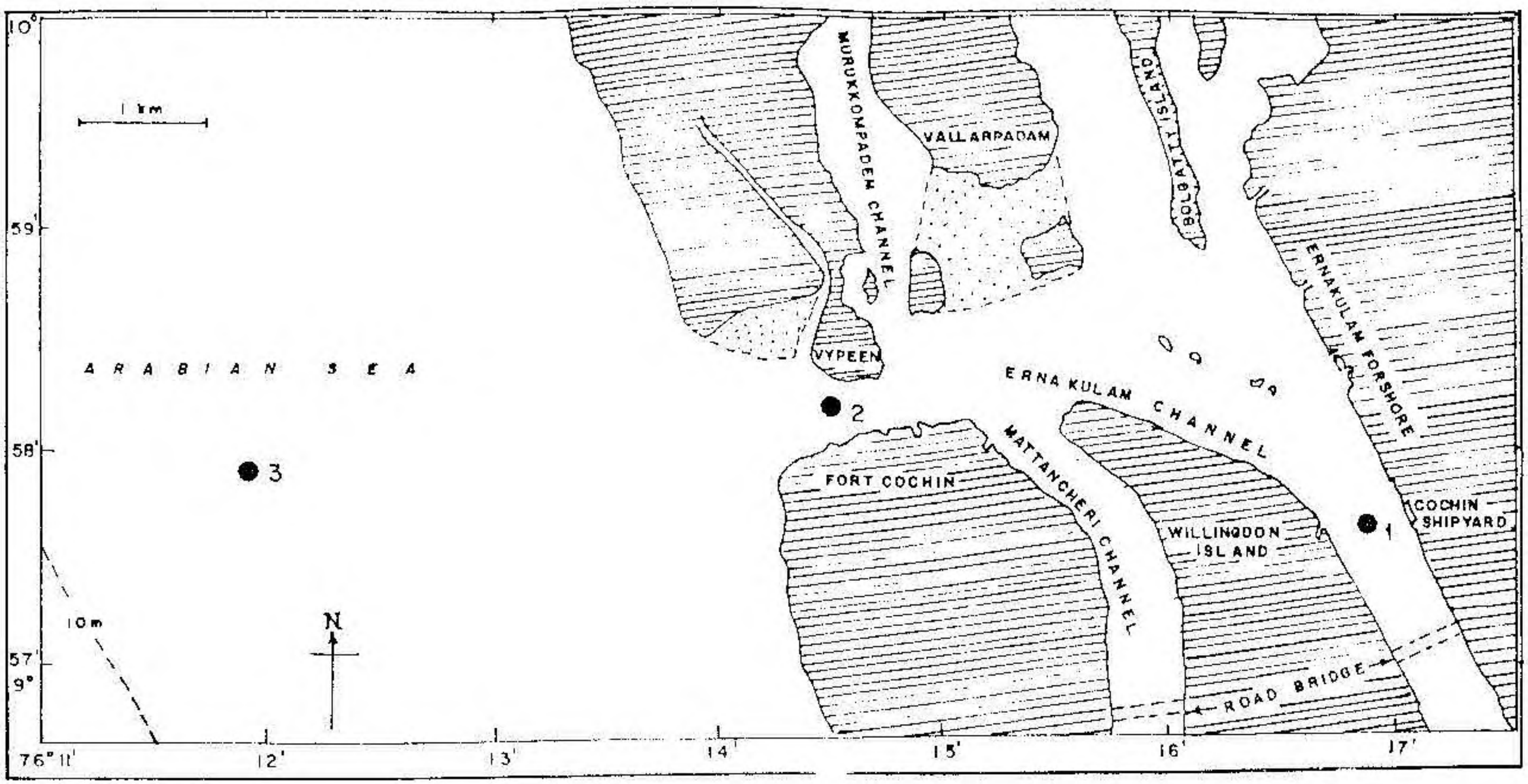
Prior to the commencement of the work, a preliminary survey was conducted in the Ernakulam channel of the Cochin backwater during the first week of May 1991 to fix up the sampling stations and the time of collection for regular weekly sampling. For this purpose, water samples were collected from different areas at different hours of the day taking into account the differences due to high and low tides and analysed. Based on the results obtained, three stations were selected carefully in the study area at almost equal distance of about 5 kms from each other so as to be representatives of the respective zones. To keep uniformity, the time of sampling was fixed at 0830-1030 hrs. for the regular weekly collection. For the monthly diurnal observations, the middle station was fixed. The Indian Tide Table was referred to fix up the suitable date as far as possible to get the maximum high tidal effect; and the time was fixed from 0700 to 1900 hrs. to get the bihourly data.

Study area

The present study was confined to the Ernakulam channel in the Cochin backwater extending between the road-cum-railway bridge (in the south) and the Fairway buoy (Fig. 1). To facilitate easy programming and collection of the data, the study area was divided into three units viz: (1) The lesser saline zone; (2) Middle zone having freshwater and marine influence; and (3) The higher saline zone.

Station-1: Opposite to shipyard in the 'lesser saline zone'; the depth at station varied between 6-7 m; and this area was more influenced by freshwater influx than tidal current during the monsoon season.

FIG. 1. MAP SHOWING SAMPLING STATIONS



Station-2: At the barmouth area between the northern terminus of Fort Cochin and southern terminus of Vypeen Island; the depth at station varied between 9-10 m; and the area was influenced relatively more at the surface by the flood current during low tide in the monsoon season and tidal current at the bottom during high and low tides.

Station-3: At the Fairway buoy in the sea; depth at station varied from 9-10 m; and this area had relatively less freshwater influence and more marine influence when compared to the other two stations during the monsoon season.

Collection of environmental data

Field data:

Weekly sampling was made regularly from these three fixed stations on the same day from the second week of May to the last week of September 1991 at the prescribed time between 0830 and 1030 hrs, availing the facilities of R.V. Cadalmin-IX of the Central Marine Fisheries Research Institute. The monthly diurnal data were collected for May, June, July and September at bihourly interval from 0700 to 1900 hrs, while the tidal height was recorded every hour.

Environmental data on water temperature and water samples for dissolved oxygen and salinity were collected from the surface, mid-depth and bottom to study their relationship with zooplankton fluctuation and abundance. The rainfall data was obtained from the Daily Weather Report issued by the India Meteorology Department (IMD). Surface water temperature was measured at the site soon after collection of water samples with an accuracy of $\pm 0.1°C$ using precision mercury Thermometer (0-50°C) and temperature for mid-depth and bottom through the reversing Thermometer fitted in the Nansen's water sampler. Water samples for dissolved oxygen were collected in 125 ml narrow mouthed bottles and fixed on the spot with Winkler 'A' and 'B'. Water samples for salinity were collected in narrow mouthed air-tight plastic bottles of 100 ml capacity and transported to C.M.F.R.I. laboratory for analysis.

Laboratory analysis

Water samples brought from the field were analysed as far as possible on the same date for hydrographic parameters. Determination of salinity and dissolved oxygen were made according to the methods prescribed by Strickland and Parsons (1968).

Salinity: Estimated by Mohr-Knudsen method as described by Strickland and parsons (1968).

Dissolved oxygen: Estimated by Winkler method as described by Strickland and Parsons (1968).

Collection of Zooplankton

Poor sampling design has been perhaps the most serious defect in the studies of secondary production (Lewis, 1979).

In the preliminary survey, the sampling method was standardised to avoid any serious error in the primary data which might greatly reduce the scope for data interpretation.

Field data:

The zooplankton sampling programme included the following:

1. A weekly vertical series of samples from:

   (a) mid-depth to surface to get the zooplankton of the upper water column (surface layer) and from

   (b) near-bottom to surface to get the zooplankton of the entire column at every station for quantitative estimation;

2. A weekly series of oblique tows operated between mid-depth and surface for five minutes at every station at the speed of 1 nautical mile per hour for qualitative analysis; and

3. Monthly bihourly series of vertical sampling as cited in 1(a) & (b) from 0700-1900 hours at station-2 to understand the influence of tidal and freshwater flow.

For this purpose, the Bongo-net of 20 cm diameter and 1 m long with mesh size of 40 µm; and another net of 50 cm diameter and 2 m long with the same mesh size were used. For the vertical tows, the net attached to the wire rope released to the respective depth, (mid-depth or bottom as the case may be), alongwith sufficient weights tied with the wire rope (hanging below the net ring), was retrieved at constant speed as fast as possible with a motorized winch. The plankton samples thus collected from the vertical and oblique tows at each station were preserved in separate wide mouthed plastic bottles with 5% diluted formalin, labelled properly and transported to C.M.F.R.I. laboratory for analysis.

Analysis and estimation of zooplankton

The regular weekly/fortnightly samples collected by oblique tows at the three stations were analysed for qualitative study of zooplankton groups; while the samples obtained by the vertical tows were analysed for quantitative estimation of zooplankton groups. As the plankton samples from the backwater stations contained detritus, phytoplankton and decaying leaves, twigs etc., the displacement volume did not give satisfactory results during this season. Hence, the zooplankton biomass displacement volume was not considered in the present investigation; instead, for more accuracy, the numerical estimation of the zooplankton groups was considered in the present study.

For qualitative analysis of zooplankton groups, as far as possible, the entire sample was examined under a binocular microscope using the zooplankton counting chamber, designed by the Central Marine Fisheries Research Institute. Before counting, the larger particles such as decaying leaves, twigs etc. were removed. Whenever the sample contained more zooplankton, at the time of counting, those samples were diluted with water and brought to constant volume (500 or 1000 ml depending on the density of plankton), agitated well and subdivided once or twice by the Folsom plankton splitter. The subsample was examined under binocular microscope using the zooplankton counting chamber and the percentage composition of the different zooplankton groups were assessed.

For quantitative (numerical) estimation of the different zooplankton groups also, the same principle was followed for the samples obtained by vertical tows. In this case, before subsampling, the larger sized zooplankton groups such as siphonophores, medusae, larger decapod larvae and fish fry were sorted out from the entire sample and were numerically quantified to get the correct estimate of the zooplankton groups; while the subsample was counted for the other zooplankton groups under the binocular microscope using the zooplankton counting chamber. Comparison of the number of zooplankton in a subsample with the total number in a sample showed that the subsampling technique produced an unbiased estimate of the mean.

Considering the subdivisions, the counts obtained for the subsample were extrapolated correspondingly to get the correct estimates of the different zooplankton groups in the entire sample.

To get the actual counts of the different zooplankton groups from the bottom layer (bottom to mid-depth), the estimated values obtained for the sample from the upper water column (surface to mid-depth) were subtracted from the respective counts of the groups obtained for the entire water column (bottom to surface). The values thus obtained for the different groups from the two water columns were separately estimated as 'nos. per m^3

of water' using the formula $\pi r^2 d$ where 'r' is the radius of the net ring in metre and 'd' is the depth of water column (surface to mid-depth or mid-depth to bottom as the case may be) in metres. The values thus obtained per m^3 in decimels for the different zooplankton groups were rounded off to the nearest number for better expression. The diversity index ('d') of the zooplankton population was calculated using the formula:

$$d = \frac{g}{\log_{10} N}$$

where

g = the number of zooplankton groups; and

N = Number of zooplankton individuals

Treatment of data

Since the measurements were subjected to various sources of variability, care was taken in the processing of data and as far as possible, individual values were not considered to derive at any conclusion. Taking the tidal variation into account, as far as possible, the data collected close to mid-water level irrespective of high and low tides were considered while processing the data in the present investigation.

The weekly data obtained on hydrographic parameters and zooplankton were averaged for station-wise fortnightly mean values. From the fortnightly mean, the monthly mean values were calculated for the stations as well as for the whole study area. The monthly means thus obtained for the different parameters were consolidated respectively to get the averages for the sub-seasons, viz. onset, peak and closure of south-west monsoon for the three stations. The values thus obtained from the three stations were pooled together for the respective periods to get the average picture of the study area on the different parameters for the beginning, peak and closure of monsoon.

Taking the intensity of monthly rainfall into consideration, the onset of monsoon (May), peak monsoon (June-August) and the closure of monsoon (September) were considered as 'premonsoon', 'monsoon' and 'post-monsoon' in the present investigation for convenience in the presentation of the results in Figures and Tables.

The fortnightly, monthly and seasonal data thus obtained for May-September 1991 were considered to study the quantitative abundance and fluctuations of zooplankton groups in relation to hydrographic parameters; and the fluctuations and relative abundance of the different zooplankton groups in % of total were tested month-wise and for the three sub-seasons.

The bihourly diurnal data collected on hydrography and zooplankton groups were used to understand the relationship of zooplankton abundance with tidal and freshwater flow.

Statistical analysis

Taking into account the variations due to the influence of tides and incursion of coastal 'upwelling' currents in the bottom layers, the data for the surface waters (surface to mid-depth) alone were considered for the statistical treatment in relation to the environmental parameters.

To study the relationship between total counts of zooplankton and various groups like copepods, chaetognaths, cladocerans, lucifers, decapod larvae and fish eggs & larvae with environmental parameters like rainfall, temperature, salinity and dissolved oxygen, linear correlation coefficients were worked out and tested for statistical significance. Similarly the relationship between total zooplankton count and tidal amplitude also was studied by working out correlation coefficients in respect of both surface and bottom layers. Analysis of variance technique was used to establish whether the zooplankton counts vary significantly in the different stations and in surface and bottom layers.

The general conclusions made in this dissertation were based on specific observations derived from the zone-wise analysis and from the practical knowledge gained in the field.

R E S U L T S

1. THE ENVIRONMENT

The physico-chemical properties have considerable influence on the fluctuation of the fauna and flora in the estuarine environment. Along the Ernakulam channel of the Cochin backwater, where the investigation was carried out during May-September 1991 (Fig. 1), depth to bottom varied from 6-7 m at station-1 and 9-10 m at stations 2 & 3 by the influence of tidal and flood flow. Along the sides of this shipping channel, the waterbody had the depth ranging between 1 and 5 m. The maximum tidal amplitude recorded at station-2 during diurnal observation was 77 cm in June.

Station-wise fortnightly variations in the rainfall, water temperature, salinity and dissolved oxygen for the surface layer (upper water column from surface to mid-depth) and bottom layer (mid-depth to bottom) during the south-west monsoon season (May - September) are presented in Figs. 2-4 and for the study area as a whole (average of three stations) in Fig. 5. Station-wise monthly mean and consolidated mean values of rainfall, temperature, salinity and dissolved oxygen for the period May-September are given in Table-1. Seasonal variations of rainfall, water temperature, salinity and dissolved oxygen for the period of 'onset' (Premonsoon), 'peak' (Peak monsoon) and 'closure' (Post-monsoon) of south-west monsoon season are given station-wise for the surface and bottom layers in Table-2.

Table - 1

Distribution of temperature, salinity and dissolved oxygen

Month	Rainfall (mm)	Stn. No.	Temperature (°C)		Salinity (‰)		Dissolved oxygen (ml/l)	
			Surface	Bottom	Surface	Bottom	Surface	Bottom
May	80	1	31.95	29.95*	24.00	27.30	3.38	3.14
		2	31.95	29.88	27.61	29.49	3.32*	3.17
		3	32.05*	28.83	30.83*	33.87	3.72	3.51
June	1492	1	28.70	28.19	02.66	09.66*	3.99	3.93*
		2	29.22	28.22	03.72	17.76	4.27	3.49
		3	28.59	26.30	14.58	33.32	3.93	2.75
July	541	1	28.40	26.30	01.18*	24.50	4.77	2.47
		2	28.28	25.98	02.59	25.78	4.30	2.48
		3	27.28	25.70	12.65	33.15	4.69	1.72
August	433	1	28.19	26.59	01.29	17.44	4.27	3.12
		2	28.04	26.47	02.36	15.16	4.10	3.13
		3	26.83*	24.87*	15.09	33.13	3.86	1.32*
September	54	1	27.75	27.45	25.19	30.13	3.56	2.24
		2	27.70	27.65	29.09	29.76	3.64	2.36
		3	27.60	27.35	29.00	34.51*	4.82*	2.52
May-September	2600	1	29.00	27.70	10.86	21.81	3.99	2.98
		2	29.04	27.64	13.07	23.59	3.93	2.93
		3	28.47	26.61	20.43	33.60	4.20	2.36
Average for study area			28.84	27.32	14.79	26.32	4.04	2.76
			28.08		20.56		3.40	

*Minimum and maximum values

Table - 2

Seasonal distribution of temperature, salinity and dissolved oxygen

Sub-seasons	Rainfall (mm)	Stn. No.	Temperature (°C)		Salinity (‰)		Dissolved oxygen (ml/l)	
			Surface	Bottom	Surface	Bottom	Surface	Bottom
Onset of monsoon (Premonsoon)	80	1	31.95	29.95	24.00	27.30	3.38	3.14
		2	31.95	29.88	27.61	29.49	3.32	3.17
		3	32.05	28.83	30.83	33.87	3.72	3.51
		Av.	31.98	29.55	27.48	30.22	3.47	3.27
Peak monsoon (Monsoon)	2466	1	28.43	27.03	01.71	17.20	4.34	3.17
		2	28.51	26.89	02.89	19.57	4.22	3.04
		3	27.57	25.62	14.11	38.20	4.16	1.93
		Av.	28.17	26.51	06.24	23.32	4.24	2.71
Closure of monsoon (Postmonsoon)	54	1	27.75	27.45	25.19	34.12	3.56	2.24
		2	27.70	27.65	29.09	29.76	3.64	2.36
		3	27.60	27.35	29.00	34.51	4.82	2.52
		Av.	27.68	27.48	27.76	31.47	4.01	2.37

1.1. Rainfall

The Cochin backwater had the local rainfall of 2600 mm during May-September 1991 with the peak recorded in the first fortnight of June (1071 mm). The fortnightly rainfall recorded from May to September were 14, 66, 1071, 421, 205, 336, 185, 245, 0 and 54 mm in the order while the monthly values were 80, 1492, 541, 433 and 54 mm respectively showing the peak in June. The peak monsoon months (June-August) registered an aggregate rainfall of 2466 mm constituting 95% of that recorded during May-September.

1.2. Temperature

During May-September, the water temperature at surface layer showed considerable decline from the first week to second week of June (32.0 to 27.9°C) in the first fortnight with increase in rainfall, while in the bottom layer it declined from 30.6 to 28.25°C in the study area as a whole and this trend was reflected in all stations.

Remarkable lowering of bottom temperature (< 26°C) was noticed in the first and third week of July and in the third week of August at stations 1 & 2. At station-3, very low bottom temperature (< 25°C) was recorded during the third and fourth week (second fortnight) of June, third week of July and first and second fortnight of August. In general, the surface and bottom temperature were relatively low at station-3 during the peak monsoon months.

Towards the close of south-west monsoon, the mean temperature was found to increase from the first to second fortnight of September in all stations and it was 26.73-28.63 and 26.63-28.33°C at the surface and bottom waters respectively in the study area (Fig. 5).

In the study area, overall monthly mean values in the surface layer were 31.98, 28.84, 27.99, 27.68 and 27.68°C in the order with the maximum in May and minimum during August and September and that in the bottom layer were 29.55, 27.57, 25.99, 25.98 and 27.48°C in the order with the maximum in May and minimum during July and August. During the peak monsoon period (June-August), the mean values were 28.17 and 26.51°C in the surface and bottom layers respectively. The overall average for the entire water column of the study area during May-September was 28.08°C.

1.3. Salinity

In the study area, salinity showed sharp decline from the second fortnight of May to the first fortnight of June at surface (29.08 to 8.77 ‰) and bottom (31.85 to 19.93 ‰) with increase in rainfall. This decline was more pronounced between the first and second week of June in the surface layer (19.76 to 1.89 ‰) and at the bottom (28.27 to 19.56 ‰), especially at station-1 leading to almost freshwater in the second week of June at the surface (0.36 ‰) and bottom (0.54 ‰).

During June-September, unusual increase in bottom salinity was noticed at stations 1 & 2 during the third week of June (23.71 & 25.8 ‰), first week of July (33.79 & 33.43 ‰), third week of July (30.99 & 32.33 ‰), third week of August (33.44 & 30.31 ‰) and during the first week of September (33.56 & 34.19 ‰ for stations 1 & 2 respectively). Such high values in bottom waters were not noticed in the diurnal variation during June and July in relation to tidal flow (Table-3). The weekly/fortnightly variations in temperature, salinity and dissolved oxygen in the bottom layer at station-2 are presented in Table-4 to indicate the frequent rise in salinity values and simultaneous reduction in temperature and dissolved oxygen values.

Table - 3

Diurnal variation in bottom salinity (‰) at bihourly intervel

Time (Hours)	May (25-5-91)	June (27-6-91)	July (27-7-91)	September (7-9-91)
0700	26.5 (L)	1.07 (L)	2.2 (L)	26.75 (H)
0900	31.15(H)	0.70 (L)	3.6 (L)	30.67 (H)
1100	31.48(H)	7.41 (H)	11.86 (H)	34.64 (H)
1300	32.15(H)	9.82 (H)	18.90 (H)	34.60 (L)
1500	32.07(L)	16.74 (H)	23.99 (H)	33.50 (L)
1700	28.89(L)	2.14 (L)	4.22 (L)	21.40 (L)
1900	32.0 (H)	1.40 (L)	3.68 (L)	29.50 (H)

Towards the close of south-west monsoon, the mean salinity was found to increase from the second fortnight of August to first fortnight of September at surface (6.59 to 24.54 ‰) and bottom (23.86 to 34.13 ‰) in the study area (Fig. 5).

Table - 4

Variations of hydrographic parameters in the bottom layer at station-2

Date	Temperature (°C)	Salinity (‰)	Dissolved oxygen (ml/l)
16-5-91	31.35	27.49	2.52
25-5-91	28.40	31.48	3.81
1-6-91	29.40	31.15	3.73
10-6-91	28.00	24.09	3.75
15-6-91	28.20	1.47	3.70
22-6-91	30.00	25.80	3.00
27-6-91	25.80	7.41	3.53
6-7-91	25.80	33.43	1.74
11-7-91	26.50	13.34	2.96
20-7-91	24.70	32.33	1.39
27-7-91	26.90	23.99	3.84
3-8-91	26.60	2.70	3.95
9-8-91	26.60	19.63	2.74
17-8-91	27.40	8.50	4.01
22-8-91	25.10	30.31	1.83
31-8-91	26.50	18.62	2.86
7-9-91	26.90	34.19	1.45
28-9-91	28.40	25.33	3.27

In the study area, overall monthly mean values in the surface layer were 27.48, 7.82, 5.47, 6.21 and 27.76 ‰ in the order with the minimum in July and that in the bottom layer were 30.22, 20.25, 27.81, 21.91 and 31.47 ‰ with the minimum recorded in June. During the peak monsoon (June-August), the mean values were 6.24 and 23.32 ‰ in the surface and bottom layers respectively. The overall average for the entire waterbody of the study area was 20.56 ‰.

1.4. Dissolved oxygen

During May-September, stations 1 & 2 exhibited unusual decline in dissolved oxygen level frequently in the bottom layer such as during the third week of June (2.8 & 3.0 ml/l), first week of July (2.02 & 1.74 ml/l), third week of July (1.49 & 1.39 ml/l), third week of August (1.19 & 1.83 ml/l) and during the first fortnight of September (1.87 & 1.45 ml/l respectively). At station-3, the bottom values were less than 1.6 ml/l during first and third week of July, first and second fortnight of August and less than 1 ml/l during the first week of September, while surface waters did not show such fluctuations at stations 1-3.

In the study area, fortnightly data showed that dissolved oxygen in surface waters varied from 3.2 to 4.2 ml/l during May-September except the high value of 5.16 ml/l observed during the first fortnight of July (average of three stations) and the minimum value was recorded during the first fortnight of May while the values in the bottom waters ranged between 1.38 and 4.1 ml/l during the period of investigation (Fig. 5).

In the study area, overall monthly mean values (average of three stations) at surface were 3.47, 4.06, 4.59, 4.07 and 4.01 ml/l in the order with the minimum in May and maximum in July; while at the bottom, the values were 3.27, 3.39, 2.23, 2.53 and 2.37 ml/l in the order with the minimum recorded in July and maximum in June. During the peak monsoon period (June-August), the mean values were 4.24 and 2.71 ml/l in the surface and bottom layers respectively. Overall average for the study area in the entire waterbody during May-September was 3.4 ml/l.

2. ZOOPLANKTON COMPOSITION

During May-September the groups of zooplankters encountered in the collections were marine, estuarine and freshwater members of copepods and cladocerans, marine and estuarine chaetognaths, lucifers, medusae, decapod larvae, fish eggs & larvae, appendicularians, ctenophores, doliolids, dinoflagellates, isopods, ostracods, planktonic polychaetes and siphonophores.

Considering both their frequency of occurrence and numerical abundance (excluding unusual swarms) in the samples for June-September, groups like copepods, chaetognaths, cladocerans, lucifers, medusae, decapod larvae and fish eggs & larvae were treated separately as individual groups. While the groups constituting less than 0.5% in total (excluding the blooming/ swarming samples) during June-September were included under 'others' in the present investigation.

3. NUMERICAL ESTIMATION

Based on the collection and qualitative and quantitative analysis of 144 regular and 56 diurnal zooplankton samples for the period May-September, numerical estimations of total zooplankton and of the important groups such as copepod, chaetognath, cladocera, lucifer, medusae, decapod larvae and fish eggs & larvae were made per m^3 of water for the three stations separately and for the study area as a whole covering the whole south-west monsoon season commencing from the onset of rainfall (May) to the closure of this season (September).

3.1. Total zooplankton

Numerical estimations of total number of zooplankton for the south-west monsoon season at the three stations in the surface layer (surface to mid-depth) and bottom layer (mid-depth to bottom) and for the study area in general (average of three stations) are given in Table-5.

Table - 5

Overall estimation of total zooplankton (nos/m^3) for the period May-September

Station	Surface	Bottom	Entire column
1	3470	3523	3497
2	1336	1761	1549
3	1919	2276	2098
Average (1-3)	2242	2520	2381

Based on the averages of the three stations, the total zooplankton number for the entire study area covering the entire water column was estimated as 2381/m^3 during the south-west monsoon season (May-September). The station-wise abundance was estimated as 3497, 1549 and 2098 numbers per m^3 of water respectively. The overall average in the surface and bottom layers were 2242 and 2520 nos/m^3 respectively.

3.2. Important groups

Station-wise numerical estimations of copepod, chaetognath, cladocera, lucifer, medusae, decapod larvae, fish eggs & larvae and 'others' for the south-west monsoon season in the surface and bottom layers are given in Table-6 and for the study area as a whole in Table-7.

3.2.1. Copepods: Station-wise mean values for the surface layer (surface to mid-depth) were 190, 233 and 414 nos/m^3 and for the bottom layer (mid-depth to bottom) 240, 285 and 841 nos/m^3 for stations 1, 2 and 3 respectively showing an increasing trend from stations 1 to 3. The overall mean values for the surface and bottom layers were 279 and 455 nos/m^3 respectively and for the entire water column 367 nos/m^3 during the south-west monsoon period commencing from May to September.

3.2.2. Chaetognaths: Mean values for the surface layer were 39, 55 and 131 nos/m^3 and for the bottom 39, 65 and 176 nos/m^3 for the stations 1, 2 & 3 respectively showing an increasing trend from station-1 to station-3. The overall mean values for the surface and bottom layers were 75 and 93 nos/m^3 and for the entire water body 84 nos/m^3 of water during May-September.

3.2.3. Cladocerans: Station-wise mean values for the surface layer were 283, 209 and 156 nos/m^3 and for the bottom 373, 320 and 24 nos/m^3 respectively showing a decreasing trend from station-1 to station-3; and the overall mean values were 216 and 239 nos/m^3 for the surface and bottom layers respectively with the mean of 227 nos/m^3 for the entire waterbody during May-September.

3.2.4. Lucifers: Mean values for the upper water column were 144, 138 and 184 nos/m^3 and for the bottom layer 153, 188 and 226 nos/m^3 for stations 1, 2 and 3 respectively with the maximum number in surface and bottom layers observed at station-3. The overall mean values for the surface and bottom layers were 155 and 189 nos/m^3 respectively and for the entire water column in the study area 172 nos/m^3 during May-September.

3.2.5. Medusae: Station-wise mean values for the surface layer were 15, 15 and 39 nos/m^3 and for the bottom layer 6, 16 and 38 nos/m^3 respectively showing increase at station-3. The overall mean values for the study area in surface and bottom layers were 23 and 20 nos/m^3 respectively with the mean of 22 nos/m^3 for the entire water column during May-September. In general, they were less at all stations.

3.2.6. Decapod larvae: Mean values for the surface layer were 1602, 97 and 110 nos/m^3 and for the bottom layer 2149, 92 and 95 nos/m^3 for stations 1, 2 & 3 respectively showing very high number in the surface and bottom layer at station-1. This high value was due to the swarming observed in the first week of June. At stations 2 & 3, the distribution at surface and bottom layers ranged between 92 and 110 nos/m^3 during the period of investigation.

3.2.7. Fish eggs and larvae: Station-wise mean values recorded were 26, 17 and 37 nos/m^3 at the surface layer and 15, 16 and 38 nos/m^3 at the bottom layer respectively with the maximum observed in the surface and bottom layers at station-3. The overall mean values for the entire study area in surface and bottom layers were 27 and 23 nos/m^3 while the mean for the entire water column was 25 nos/m^3 during May-September.

Table - 6

Station-wise estimation of zooplankton groups (nos/m^3) in surface and bottom layers for the south-west monsoon period (May - September)

Groups	Station-1		Station-2		Station-3	
	S	B	S	B	S	B
Copepods	190	240	233	285	414	841
Chaetognaths	39	39	55	65	131	176
Cladocerans	283	373	209	320	156	24
Lucifers	144	153	138	188	184	226
Medusae	15	6	15	16	39	38
Decapod larvae	1602	2149	97	92	110	95
Fish eggs & larvae	26	15	17	16	37	38
Others	1171	548	572	779	848	838

3.3. Plankton blooms/swarms:

During the course of the present investigation, blooms of diatoms and dinoflagellates and swarms of decapod larvae and pelagic polychaetes were recorded in the study area. A dense swarm of decapod larvae (brachyuran zoea) was observed on

Table - 7

Estimation of zooplankton groups in the study area for the south-west monsoon period (May-September) (consolidated mean nos/m^3)

Groups	Surface	Bottom	Entire column
Copepods	279	455	367
Chaetognaths	75	93	84
Cladocerans	216	239	227
Lucifers	155	189	172
Medusae	23	20	22
Decapod larvae	603	779	691*
Fish eggs & larvae	27	23	25
Others	864	722	793

* Excluding the swarm number, the mean was estimated as 131 nos/m^3 only.

1-6-1991 amounting to 44140 and 57006 nos/m^3 in the surface and bottom layers at station-1 when the salinity was 14.4 and 20.85‰ respectively. The other two stations did not show such high values when the salinity ranged from 18.42 to 32.82 ‰.

During the third week of July (20-7-1991), a bloom of the dinoflagellate, Noctiluca was observed in the study area with the maximum number recorded in the surface layer at station-1. The estimated values were 21765 & 5541 nos/m^3, 8344 & 1592 nos/m^3 and 10955 and 2802 nos/m^3 in the surface and bottom layers at stations 1, 2 and 3 respectively when the salinity was 1.34 & 31.0 ‰, 2.41 & 32.33 ‰ and 22.71 & 34.29 ‰ respectively.

On 7-9-1991, a minor swarm of cladocera was noticed in the samples with the highest number recorded at station-1. The estimated values were 2468 & 3333 nos/m^3, 1783 & 2962 nos/m^3 and 1035 & 604 nos/m^3 in the surface and bottom layers of stations 1, 2 and 3 respectively, when the salinity values were 24.15 & 33.56 ‰, 24.65 & 34.19 ‰ and 24.81 & 34.64 ‰ respectively. Along with this, another minor swarming of pelagic polychaetes was observed with the abundance at station-2. Their estimated values for stations 1, 2 & 3 were 64, 462 and 80 nos/m^3 in the surface layer and 573, 844 and 574 nos/m^3 in the bottom layer respectively. Along with the abundance of cladocerans and pelagic polychaetes, dense blooms of Fragilaria and Ulothrix were observed in the study area with their abundance at station-2.

4. FLUCTUATION

Station-wise fortnightly fluctuations of the total zooplankton number in the surface and bottom layers for the period May-September are illustrated in Figs. 2-4 and for the study area as a whole in Fig. 5. Similarly, fortnightly variations of copepods, chaetognaths, cladocerans, lucifers, medusae, decapod larvae and fish eggs and larvae in the surface and bottom layers are illustrated in Figs. 6 & 7, 8 & 9 and 10 & 11 for stations 1, 2 and 3 and for the study area as a whole in Figs. 12 and 13 respectively.

Station-wise monthly range and mean of copepods, chaetognaths, cladocerans, lucifers, decapod larvae and fish eggs & larvae for the surface and bottom layers are shown in Figs. 14-16 and their consolidated monthly range for the entire water column in the study area during south-west monsoon period are given in Fig. 17.

Seasonal fluctuations of these zooplankton groups pertaining to the onset, peak and closure of south-west monsoon in the study area as a whole for the surface layer and bottom layer are illustrated in Figs. 18 and 19 respectively.

The monthly mean values of the important zooplankton groups for stations 1, 2 & 3 in the surface layer are given in Table-8 and for the bottom waters in Table-9. The consolidated monthly mean values for the surface and bottom waters of study area are given in Table-10 and 11 respectively. Table-12 gives the station-wise fluctuation index of different zooplankton groups in % of their mean values for the whole monsoon (May - September).

4.1. Total zooplankton

Fortnightly distribution of total zooplankton at station-1 (Fig. 2) showed three peaks in the surface and bottom layers during the first fortnight of June, second fortnight of July and first fortnight of September and their mean numbers were 15352, 11307 and 3043 per m^3 in the surface layer and 19695, 3186 and 4965 per m^3 in the bottom waters respectively. The monthly mean number per m^3 ranged from 226-7836 at surface and 692-9926 in the bottom waters with their minimum recorded in August and the maximum in June.

Station-2 (Fig. 3) showed peaks during the second fortnight of July and first fortnight of September numbering 4860 and 3163 per m^3 respectively at surface and one peak of 9829 nos/m^3 at the bottom waters during the first fortnight of September. The monthly mean values per m^3 ranged from 246 (August) to 2948 (July) at surface and 480 (August) to 5073 (September) at the bottom layer.

Station-3 (Fig-4) showed only one prominent peak of 6470 nos/m^3 at the surface during the second fortnight of July while the bottom waters had two peaks of 4045 and 3781 nos/m^3 during the first fortnight of July and of September respectively. The monthly mean numbers per m^3 ranged from 1228 to 3988 at surface and 1344 to 3131 in the bottom waters with their maximum recorded in July and minimum in May.

Overall averages in the study area (Fig. 5) showed two prominent peaks of 5706 and 7546 nos/m^3 in the surface and of 7546 and 6191 nos/m^3 in the bottom waters during the first fortnight of June and second fortnight of July respectively. The monthly mean values per m^3 ranged from 720 (August) to 4269 (July) at surface and 1264 (August) to 4212 (June) in the bottom layer, while in the entire water column of the study area, the range was 987-3717 nos/m^3 with the minimum number recorded in August and the maximum in June.

The seasonal mean values estimated for the beginning, peak and closure of south-west monsoon period as premonsoon, monsoon and postmonsoon were 1389, 2733 and 1613 nos/m^3 for the surface layer and 1604, 2573 and 3275 nos/m^3 at the bottom layer respectively. The overall mean values for the entire column were 1497, 2653 and 2444 nos/m^3 respectively in the study area.

4.2. Copepods

Fortnightly distribution of copepods at station-1 (Figs. 6 & 7) showed a peak of 504 nos/m^3 in the surface layer during the first fortnight of May while the peak of 832 nos/m^3 was noticed in the bottom waters during the first fortnight of July. The monthly mean number per m^3 ranged from 9-403 at surface and 85-499 at bottom layers with their minimum recorded in August and maximum in May and July respectively, showing higher values at the bottom waters.

Station-2 (Figs. 8 & 9) recorded a peak of 703 nos/m^3 at surface and 1326 nos/m^3 at the bottom layers during the first fortnight of July. The monthly mean number per m^3 ranged from 16-495 and 84-817 with their minimum recorded in August and maximum in July showing higher values in the bottom waters.

Station-3 (Figs. 10 & 11) showed a prominent peak ranging between 783 and 1147 nos/m^3 during second fortnight of June to first fortnight of July at the surface. The bottom waters showed a prolonged peak of high magnitude extending between the first fortnight of June and first fortnight of July reaching the maximum of 3800 nos/m^3 in the first fortnight of July. The monthly mean values per m^3 ranged from 28-790 and 160-2083 nos/m^3 at surface and bottom respectively with their minimum recorded in August and maximum in July (Tables 8 & 9).

Table - 8

Distribution of dominant zooplankton groups in the surface layer (nos/m^3)

Month	Stn. No.	Zooplankton groups							
		Copepod	Chaeto-gnath	Cladocera	Lucifer	Medusae	Decapod larvae	Fish eggs & larvae	Others
May	1	403	44	44	546	62	408	58	107
	2	411	82	13	406	36	236	23	64
	3	399	127	0	371	90	180	21	40
June	1	177	27	25	112	0	7436	34	29
	2	133	47	11	82	5	111	15	64
	3	639	196	23	166	37	121	23	153
July	1	283	0	28	29	0	22	18	5458
	2	495	55	24	113	4	45	15	2199
	3	790	131	37	155	7	67	13	2789
August	1	9	58	82	4	1	18	1	54
	2	16	62	105	35	0	21	5	4
	3	28	154	203	152	19	110	104	890
September	1	77	31	1234	30	11	127	22	206
	2	110	30	892	53	29	73	27	530
	3	215	46	518	74	40	70	25	369

Table - 9

Distribution of dominant zooplankton groups in the bottom layer (nos/m^3)

Month	Stn. No.	Zooplankton groups							
		Copepod	Chaeto-gnath	Cladocera	Lucifer	Medusae	Decapod larvae	Fish eggs & larvae	Others
May	1	291	68	38	551	4	1072	26	180
	2	289	86	3	597	52	126	29	61
	3	304	169	0	492	121	94	13	152
June	1	242	18	2	71	0	9510	1	84
	2	114	47	3	100	0	200	1	55
	3	1383	158	2	202	0	223	7	220
July	1	499	0	44	60	1	82	10	1410
	2	817	15	38	111	4	70	26	412
	3	2083	56	3	171	10	64	0	747
August	1	85	61	114	26	0	25	41	343
	2	84	115	75	29	4	27	17	130
	3	160	417	113	100	30	66	153	1582
September	1	86	51	1667	58	24	57	0	724
	2	121	65	1481	103	22	38	6	3239
	3	277	77	302	166	28	31	20	1491

Table - 10

Monthly distribution of dominant zooplankton groups (nos/m^3) in the surface layer of the study area

Month	Copepod	Chaeto-gnath	Cladocera	Lucifer	Medusae	Decapod larvae	Fish eggs & larvae	Others
May	405	84	19	441	63	274	34	70
June	316	90	20	120	14	2556	24	82
July	523	62	30	99	4	45	16	3482
August	18	91	130	63	7	50	37	316
September	134	36	881	53	27	90	25	369

Table - 11

Monthly distribution of dominant zooplankton groups (nos/m^3) in the bottom layer of the study area

Month	Copepod	Chaeto-gnath	Cladocera	Lucifer	Medusae	Decapod larvae	Fish eggs & larvae	Others
May	295	107	14	547	59	431	22	131
June	579	74	2	124	0	3311	3	120
July	1133	23	28	114	5	72	12	356
August	110	198	101	52	12	39	70	685
September	161	64	1049	109	25	42	9	1818

Table - 12

Index of fluctuation of zooplankton groups in % of mean during May-September 1991

Group	Stn. No.	Surface	Bottom	Entire water column
Copepod	1	503	640	572
	2	548	841	695
	3	365	850	608
Chaetognath	1	531	518	525
	2	409	562	486
	3	367	482	425
Cladocera	1	872	894	883
	2	853	926	890
	3	664	1258	961
Lucifer	1	481	699	590
	2	325	489	407
	3	270	328	299
Medusae	1	820	700	760
	2	480	625	553
	3	408	368	388
Decapod larvae	1	2755	2653	2704
	2	572	776	674
	3	432	1039	736
Fish eggs & larvae	1	556	1527	1042
	2	235	450	343
	3	1378	1676	1527

Fortnightly distribution of copepods in the study area for surface and bottom waters is illustrated in Figs. 12 & 13. In the study area as a whole, the monthly mean values of copepods per m^3 ranged from 18-523 at surface and 110-1133 at the bottom with their minimum recorded in August and maximum in July showing higher values at the bottom layer (Tables 10 & 11). The mean values in the entire water column per m^3 were 350, 448, 828, 64 and 148 for May, June, July, August and September respectively with the maximum in July and minimum in August.

Mean values estimated for the three subseasons (May, June-August, September) in the entire water column were 350, 446 and 148 nos/m^3 respectively. The fluctuation index of copepods in % of mean for the whole south-west monsoon period (May-September) in the entire water body showed high value (695) at station-2 and low (572) at station-1; and in general, all the stations recorded high values at the bottom layer than at surface (Table-12).

4.3. Chaetognaths:

Fortnightly distribution of chaetognaths at station-1 (Figs. 6 & 7) showed a peak of 104 nos/m^3 in the surface waters during the first fortnight of August and two peaks of same magnitude at the bottom waters during the second fortnight of May and first fortnight of August (100 & 101 nos/m^3 respectively). The monthly mean number per m^3 ranged from 0 to 58 at surface and 0 to 68 at bottom with nil value recorded during July and high values during May and August.

Station-2 (Figs. 8 & 9) recorded two peaks of 137 and 113 nos/m^3 during the second fortnight of May and first fortnight of August in the surface layer. Bottom waters also showed the same peaks amounting to 136 and 184 nos/m^3 respectively. The monthly mean showed high values during May and August at surface and bottom and low values in July and September.

At station-3, surface waters (Fig. 10) showed relatively high mean values per m^3 during the second fortnight of May (144), first fortnight of June (227), second fortnight of June (164), first fortnight of July (172), and first and second fortnight of August (173 & 134) with the highest value noticed during the first fortnight of June. Bottom waters (Fig 11), in general, showed relatively higher values than at the surface with very high values ($>$300 nos/m^3) recorded during the first and second fortnight of August (494 and 339 nos/m^3 respectively). Monthly mean values (Tables 8 & 9) showed unusually high number of 417 per m^3 in the bottom waters during August when the surface layer showed 154 nos/m^3. The other monthly mean values did not exceed 200 nos/m^3 in bottom waters. During May, the mean values were 127 and 169 nos/m^3 in the surface and bottom waters respectively. In general, low values were recorded during July and September (56 and 46 nos/m^3 respectively).

Fortnightly distribution of chaetognaths in the study area for the surface and bottom waters is presented in Figs. 12 & 13. The monthly mean values in the entire water column of study area per m^3 of water were 96, 82, 48, 145 and 50 for May, June, July, August and September respectively, with the minimum in July and the maximum in August.

Mean values estimated for the three sub-seasons (beginning, peak and closure of monsoon) in the entire water column of the study area were 96, 92 and 50 nos/m^3 respectively. The fluctuation index of chaetognaths in % of mean for the whole season in the entire water body showed high values (525) at station-1 and low at station-3 (425) (Table-12).

4.4. Cladocerans

Fortnightly distribution of cladocerans at station-1 (Figs. 6 & 7) showed high values of 80 nos/m^3 at surface and 64 nos/m^3 at the bottom waters during the second fortnight of May and decline during June and July at surface and in June at the bottom waters. Then, the surface waters showed progressive increase of cladocerans from the first fortnight of August (64 nos/m^3); while such an increase was noticed in the bottom waters from the second fortnight of July (64 nos/m^3), leading to a swarm in the first fortnight of September amounting to 2468 nos/m^3 at surface and 3333 nos/m^3 at the bottom waters, resulting in an abrupt decline showing nil value during the second fortnight of September at surface and bottom layers. Monthly mean values per m^3 showed minimum (less than 30 nos/m^3) in June and maximum in September (1234 and 1667 nos/m^3 at surface and bottom respectively). In general, the values were higher in bottom waters.

Station-2 (Figs. 8 & 9) recorded low values (less than 30 nos/m^3) during May, June and July at surface and upto the first fortnight of July in the bottom waters. As observed at station-1, an increasing trend was observed at surface and bottom leading to the peak of 1783 and 2962 numbers per m^3 at surface and bottom respectively during the first fortnight of September, while the second fortnight of September showed exclusive absence of cladocerans at this station also. Monthly mean values showed the maximum of 892 and 1481 nos/m^3 at surface and bottom waters respectively during September.

Station-3 (Figs. 10 & 11) in general showed very low values (less than 30 nos/m^3) during the two fortnights of May, June and July showing relatively higher values at the surface. From the first fortnight of August, the values shot up to around 200 nos/m^3 at surface and between 100 and 125 at the bottom during the first and second fortnight of August leading to the peak of 1035 and 604 nos/m^3 in the first fortnight of September at the surface and bottom waters respectively. As in the case of stations-1 and 2, cladocerans were absent at this station during the second fortnight of September. Monthly mean values ranged from nil (May) to 518 and 302 nos/m^3 (September) at surface and bottom respectively.

Fortnightly mean values of cladocerans in the study area as a whole for surface and bottom waters are illustrated in Figs. 12 & 13 respectively. The monthly mean values in the entire column of the study area from May to September were 17, 11, 29, 116 and 965 nos/m^3 respectively with the minimum recorded in June and the maximum in September.

Mean values estimated for the three sub-seasons (May, June-August, September) in the entire water column of the study area were 17, 52 and 965 nos/m^3 respectively. The fluctuation index in % of mean values for the south-west monsoon period in the entire water column showed high values of 883, 890 and 961 in the order for stations 1, 2 and 3 respectively.

4.5. <u>Lucifers</u>

Fortnightly distribution of lucifers at station-1 (Figs. 6 & 7) showed increase in values of 248 and 183 nos/m^3 in the first fortnight of May leading to the peak of 693 and 1069 nos/m^3 at surface and bottom respectively during the second fortnight of May; which showed a decline in the next fortnight to the values of 173 and 105 nos/m^3 at surface and bottom respectively. No remarkable increase was noticed during the rest of the fortnight except the slight increase in values between 50-120 noticed during the second fortnight of July and first fortnight of September. August registered the lowest values and May showed the mean of 546 and 551 nos/m^3 at surface and bottom respectively.

Station-2 (Figs. 8 & 9) also showed almost the same trend as noticed at station-1 in the surface and bottom waters in general; with the peak of 448 and 919 nos/m^3 noticed in the second fortnight of May. The mean values obtained for these two water columns during the second fortnight of July were 219 and 222 nos/m^3 and for the first fortnight of September were 80 and 165 nos/m^3 respectively. May registered the highest monthly mean of 406 and 597 nos/m^3 while low values during August of 35 and 29 nos/m^3 at surface and bottom waters respectively.

Station-3 (Figs. 10 & 11) also showed the highest values in the first and second fortnight of May at the surface (339 & 403 nos/m^3) and at the bottom (240 and 744 nos/m^3 respectively). The mean values obtained at the surface and bottom waters were 239 and 328 during the second fortnight of June, 281 and 310 during the second fortnight of July, 260 and 143 during the second fortnight of August and 112 and 273 nos per m^3 during the first fortnight of September respectively with intermediate decline in between these fortnights. Monthly mean values showed the maximum in May (371 and 492 nos/m^3).

Fortnightly distributions of lucifers in the study area for surface and bottom waters are illustrated in Figs. 12 & 13. The monthly mean values for the entire water column in the study area were 494, 122, 107, 58 and 81 nos/m^3 during May-September respectively, with the maximum recorded in May and minimum in August.

Mean values estimated for the three sub-seasons (pre-monsoon, peak monsoon and postmonsoon) in the entire water column during south-west monsoon period were 494, 95 and 81 nos/m^3

respectively. The fluctuation index of lucifers in % of mean for May-September in the entire water column showed highest value at station-1 (590) and the lowest at station-3 (299). In general, the bottom waters showed higher values at all stations.

4.6. Medusae

Fortnightly distribution of medusae at station-1 (Figs. 6 & 7) showed the peak of 123 nos/m^3 in the surface waters during the second fortnight of May. During peak monsoon period (June-August), they were absent or very few in numbers in the surface and bottom waters. In the first fortnight of September their occurrence was noticed as 22 and 42 nos/m^3 at the surface and bottom respectively. The monthly mean values per m^3 ranged from nil (June) to 62 (May) at surface and 24 (September) at bottom.

At station-2 (Figs. 8 & 9), their distribution showed almost the same trend in the surface and bottom waters with the peak during the second fortnight of May (72 and 100 nos/m^3) and during the first fortnight of September (47 and 37 nos/m^3 respectively). Monthly mean values showed maximum of 36 nos/m^3 at surface and 52 nos/m^3 at bottom during May.

Station-3 (Figs. 10 & 11) also showed the same trend as observed at stations 1 and 2. During the second fortnight of May, their numbers per m^3 were 159 and 140 and during the first fortnight of September, 62 and 44 at the surface and bottom waters respectively. Their mean values per fortnight during

June-August were higher than those observed at stations 1 and 2, varying between nil and 32 nos/m^3. Monthly mean values showed the maximum in May (90 and 121 nos/m^3 at surface and bottom respectively).

Fortnightly distributions of medusae in the study area for the surface and bottom waters are given in Figs. 12 & 13. The monthly mean values per m^3 ranged from 4 to 63 nos/m^3 at surface and nil to 59 nos/m^3 at the bottom waters with the maximum recorded in May and the minimum in July and June respectively. The mean values for the entire area during May-September were 61, 7, 4, 9 and 26 nos/m^3 respectively, with the maximum recorded in May and minimum in July.

Mean values estimated for the three sub-seasons (beginning, peak and closure of monsoon) were 61, 7 and 26 nos/m^3 respectively in the entire water column of the study area. The fluctuation index in % of mean for the whole monsoon period (May-September) in the entire water column varied from 388 at station-3 to 760 at station-1.

4.7. Decapod larvae

Fortnightly distribution at station-1 (Figs. 6 & 7) showed higher values during the first and second fortnight of May (289 and 526 nos/m^3) in the surface waters leading to the swarming of decapod larvae during the first fortnight of June amounting to 14721 nos/m^3. From the second fortnight of June the number came down to below 50 nos/m^3 till the end of August.

The two fortnights in September showed slight increase in the surface waters (95-160 nos/m^3). The bottom waters at station-1 showed relatively higher values than at surface from the first fortnight of May to the first fortnight of June and the values were 1125, 1019 and 19012 nos/m^3 respectively. In the second fortnight of June, the swarm disappeared giving rise to very low values (Fig. 7). The increase at the bottom waters during September was not significant (50-64 nos/m^3). Monthly mean values showed minimum in August and maximum in June.

Station-2 (Figs. 8 & 9) showed the peak during the first fortnight of May (332 nos/m^3). During the second fortnight of May and first fortnight of June there was reduction in decapod larvae ranging between 139 and 200 nos/m^3 in the surface waters, while the bottom waters did not show the peak during the first fortnight of May. During May and June, the fortnightly distribution ranged from 108-258 nos/m^3 in the bottom waters while the range between July to September was 24-112 nos/m^3 during the second fortnight of August and first fortnight of July respectively. Monthly mean values showed the maximum of 236 nos/m^3 at surface in May and 200 nos/m^3 at the bottom in June.

Station-3 showed almost the same trend in distribution and number in the surface waters as observed in station-2 (Fig. 10), while the bottom waters showed an increase to the extent of 433 nos/m^3 during the first fortnight of June. The other fortnightly mean values were relatively lesser than that noticed at the surface. Station-3 also showed the maximum monthly mean of 180 nos/m^3 at surface in May and 223 nos/m^3 at the bottom in June.

Fortnightly distributions of decapod larvae in the surface and bottom waters of the entire study area are illustrated in Figs. 12 & 13 respectively. The monthly mean values per m^3 ranged from 45 (July) - 2556 nos/m^3 (June) in the surface waters and from 39 (August) to 3311 nos/m^3 (June) and for the entire water column the monthly mean values were 353, 2934, 59, 45 and 66 nos/m^3 for May-September respectively with the maximum observed in June and minimum in August.

Mean values for the three sub-seasons (May, June-August, September) in the entire water column of the study area were 353, 1012, and 66 nos/m^3 respectively. The fluctuation index in % of mean for the whole monsoon period (May-September) in the entire water column showed high values of 2704 at station-1 while stations 2 and 3 recorded 674 and 736 respectively.

4.8. Fish eggs and larvae

Fortnightly distribution at station-1 (Figs. 6 & 7) showed a peak of 96 nos/m^3 in surface waters during the second fortnight of May and its magnitude was less in the bottom waters. In the latter half, a magnitude of 81 nos/m^3 was observed in the bottom waters only during the second fortnight of August while the surface waters alone recorded 44 nos/m^3 during the second fortnight of September. During June and July, they were relatively more in the surface waters. Monthly mean values were high to the extent of 58 nos/m^3 in surface waters during May and 41 nos/m^3 in bottom waters during August.

The surface waters in station-2 recorded high number of 41/m^3 during the second fortnight of May and 32/m^3 during the first fortnight of September (Fig. 8). In general, the frequency of occurrence was more here than at station-1. The bottom waters showed higher values of 27 & 30 nos/m^3 during the first and second fortnight of May, 52 nos/m^3 during the first fortnight of July and 27 nos/m^3 during the second fortnight of August (Fig. 9). Monthly mean showed higher values (25-30 nos/m^3) during May and September at surface and during May and July in the bottom waters.

At station-3, fish eggs and larvae were represented in all the fortnights except the first fortnight of September in the surface waters with the peak of 186 nos/m^3 observed during the second fortnight of August (Fig. 10), while its number went up to 276/m^3 in the bottom waters (Fig. 11). Monthly mean showed higher values at surface and bottom during August and lowest in July.

Fortnightly mean values of fish eggs and larvae in the study area as a whole for the surface and bottom waters are presented in Fig. 12 & 13 respectively. The mean monthly values for the entire water column in the study area were 28, 14, 14, 54 and 17 nos/m^3 for May-September respectively with the maximum recorded in August.

Mean values estimated for the three sub-seasons within the southwest monsoon period (onset, peak and closure of monsoon) in the entire water body of the study area were 28, 27 and 17 nos/m^3 respectively. The fluctuation index values in % of mean for the south-west monsoon period in the entire water column were 1042, 343 and 1527 for stations 1, 2 and 3 respectively.

4.9. Others

Fortnightly distribution of miscellaneous groups together at station-1 showed a peak in the second fortnight of July dominated by Noctiluca amounting to 10913 nos/m^3 while the bottom waters recorded two high values during the second fortnight of July amounting to 2783 and the other in the first fortnight of September numbering 1324 per m^3. Monthly mean recorded high values of 5458 and 1410 nos/m^3 at the surface and bottom respectively.

Station-2 recorded the peak of 4223 nos/m^3 in the second fortnight of July and another high value of 980 nos/m^3 during the first fortnight of September. The bottom waters also exhibited the peaks in the same period. But, the first one was of lesser magnitude (796 nos/m^3) while the second one was of high magnitude leading to 6442 nos/m^3. The highest monthly mean values were 2199 nos/m^3 at surface in July and 3288 nos/m^3 at the bottom in September.

Station-3 showed three higher values in the surface layer in the decreasing order during the second fortnight of July (5574 nos), first fortnight of August (1335 nos) and during the first fortnight of September (622 nos per m^3) respectively. The bottom waters showed three high values in the increasing order during the second fortnight of July (1452 nos), second fortnight of August (2293 nos) and in the first fortnight of September (2909 nos/m^3) respectively. The highest monthly mean values were 2789 nos/m^3 at surface in July and 1582 nos/m^3 at the bottom during August.

The monthly mean values in the entire water column of the study area were 101, 101, 2169, 501 and 1094 nos/m^3 for May-September respectively showing the highest mean in July and lowest during May and June, while the seasonal mean values for the beginning, peak and closure of monsoon were 101, 923 and 1049 nos/m^3 respectively.

5. RELATIVE ABUNDANCE

5.1. Total zooplankton

In the study area, the monthly abundance of total zooplankton varied from 6.34% in August to 38.11% in July in the upper water column from surface to mid-depth and from 10.03% in August to 33.44% in June in the bottom waters (Fig. 23). For the entire water column of the study area the range was between 8.19% and 31.1% during August and June respectively. Season-wise analysis showed 22.7, 40.23 and 37.07% during the onset, peak and closure of south-west monsoon respectively in the entire waterbody of study area.

The diversity indices of zooplankton for the above cited three sub-seasons (Table-13) were 2.15, 2.0 and 2.16 at station-1, 2.28, 2.56 and 2.2 at station-2 and 2.28, 2.22 and 2.35 at station-3 respectively when the percentage abundance of total zooplankton at the three stations were 48.95, 21.68 and 29.37 respectively in the entire study area.

Table - 13

Diversity index of zooplankton at different stations during onset, peak and closure of monsoon

Stations	Sub-seasons		
	Onset (Premonsoon)	Peak (Peak monsoon)	Closure (Postmonsoon)
Station-1	2.15	2.00	2.16
Station-2	2.28	2.56	2.20
Station-3	2.28	2.22	2.35

5.2. Zooplankton groups

The month-wise relative abundance of important zooplankton groups at surface and bottom layers for the stations 1, 2 and 3 are given in Figs. 20, 21 and 22 respectively; and for the study area is illustrated in Fig. 23. Fig. 24 gives the consolidated month-wise picture of the entire water column in the study area.

In the entire water column of the study area (Fig. 24) the dominant groups encountered in the different months were lucifers (32.93%) and copepods (23.78%) in May, decapod larvae (78.98%) and copepods (11.78%) in June, copepods (31.39%) in July, chaetognaths (14.24%) and cladocerans (13.15%) in August, and cladocerans (44.81%) in September.

The percentage abundance of the different groups at the beginning, peak and closure of south-west monsoon period for the entire water column in the study area formed 37.08, 47.25 and 15.67% for copepods; 40.34, 38.66 and 21.00% for chaetognaths; 1.64, 5.03 and 93.33% for cladocerans; 73.73, 14.18 and 12.09% for lucifers; 64.90, 7.45 and 27.65% for medusae; 24.67, 70.72 and 4.61% for decapod larvae; 38.89, 37.5 and 23.61% for fish eggs and larvae; 4.77, 43.58 and 51.65% for others respectively.

6. INFLUENCE OF ENVIRONMENTAL FACTORS ON ZOOPLANKTON FLUCTUATION

6.1. Influence of rainfall and freshwater flow

The mean zooplankton numbers during the onset and peak monsoon in the study area were estimated as 1497 and 2653 nos. per m^3 when the rainfall was 80 and 2466 mm respectively, while the number during the closure of monsoon was 2444 nos. per m^3 of water as against the local rainfall of 54 mm only.

FIG. 2.
FLUCTUATIONS IN HYDROGRAPHY & ZOOPLANKTON (Stn. 1)

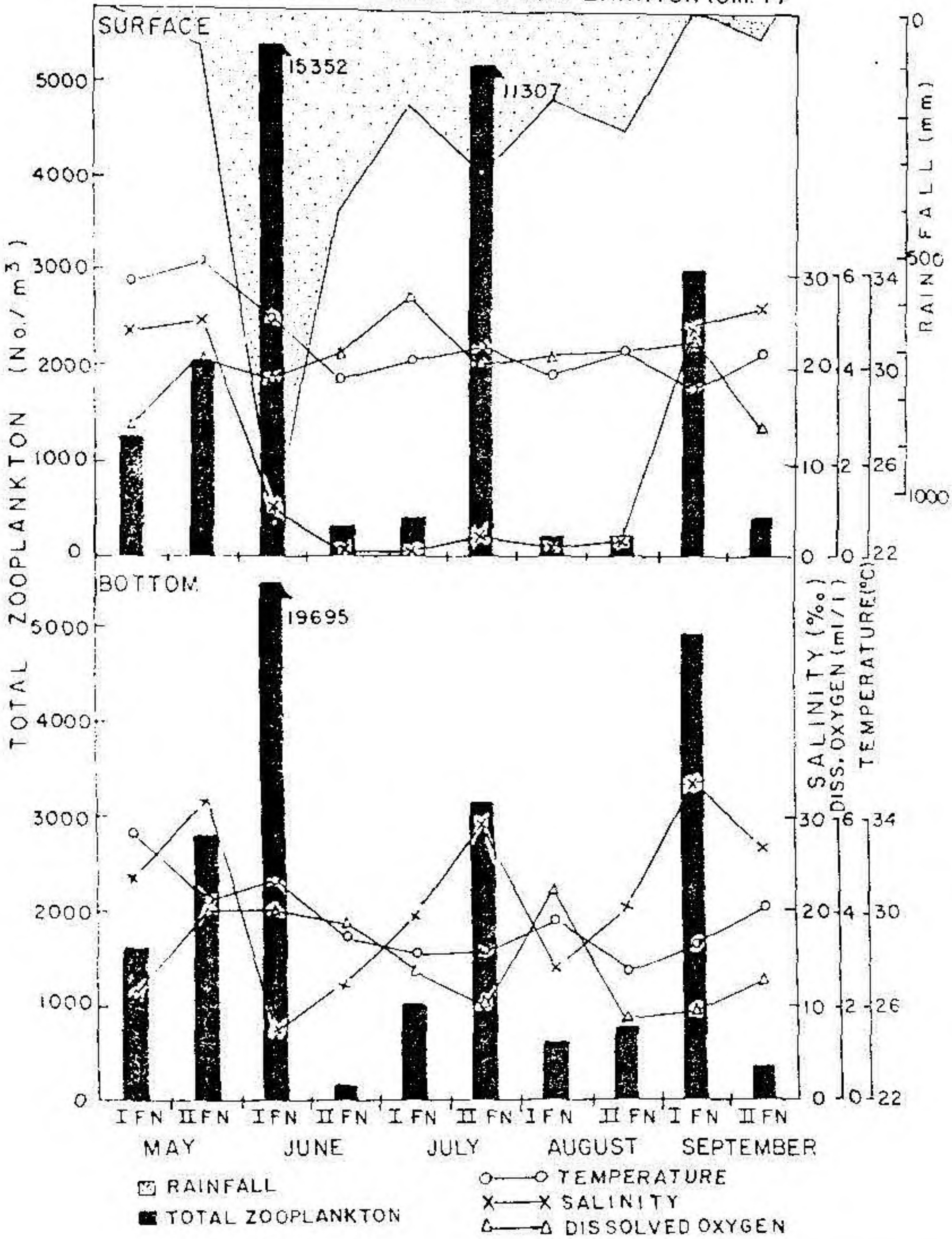


FIG. 3.
FLUCTUATIONS IN HYDROGRAPHY & ZOOPLANKTON (Stn.2)

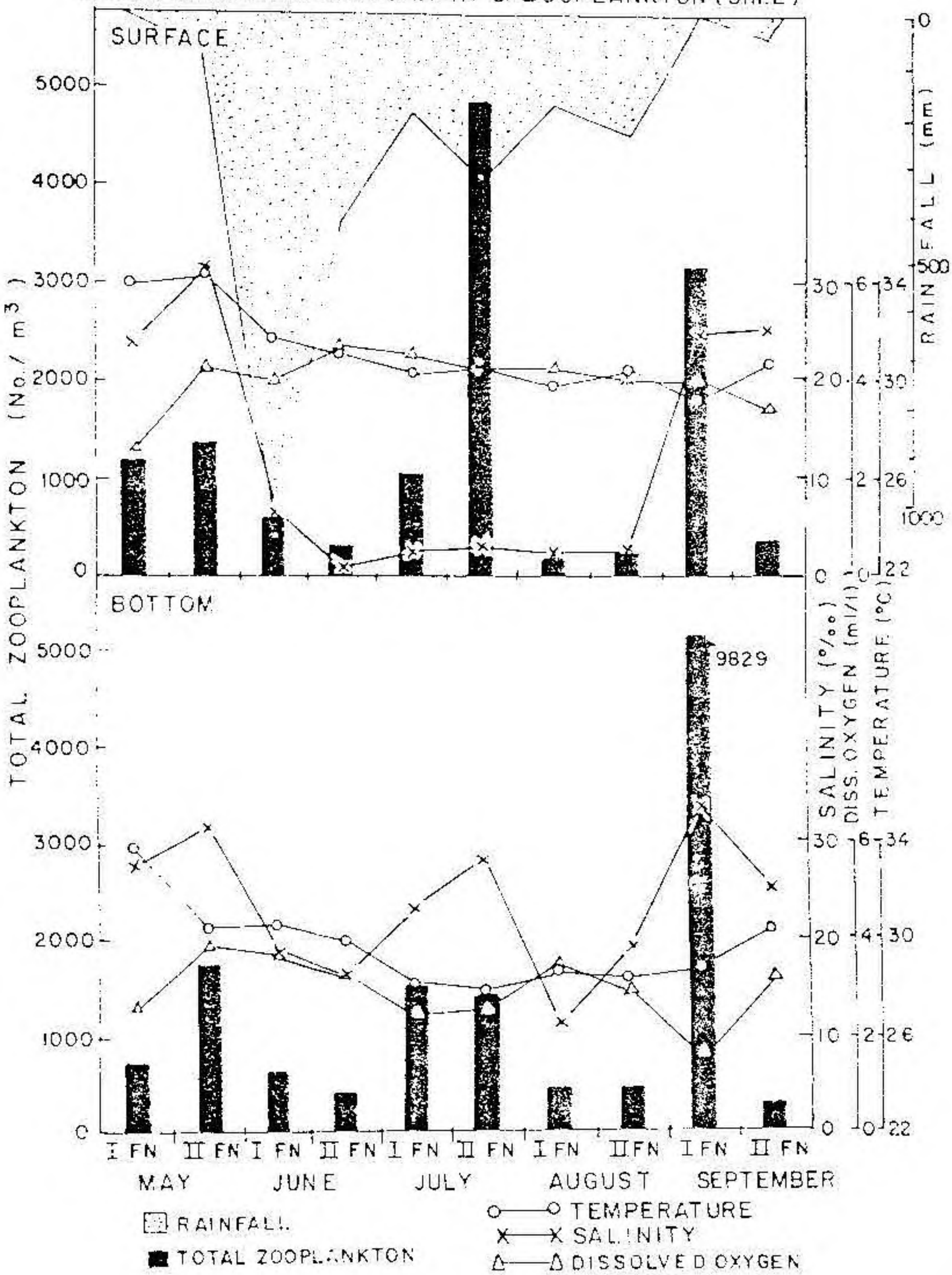


FIG. 4.

FLUCTUATIONS IN HYDROGRAPHY & ZOOPLANKTON (Stn. 3)

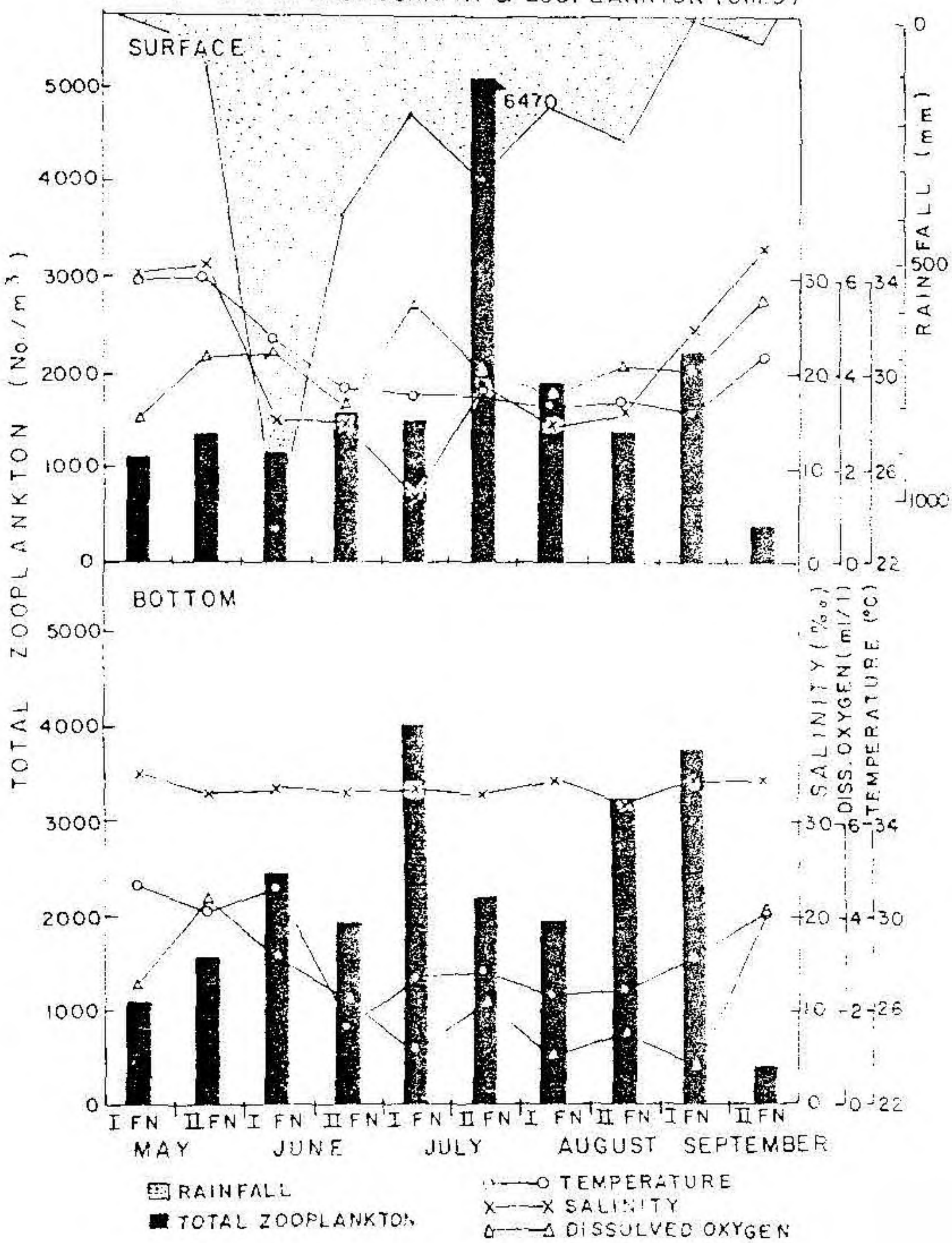


FIG. 5.

FLUCTUATIONS IN HYDROGRAPHY & ZOOPLANKTON (Av.Stns.1-3)

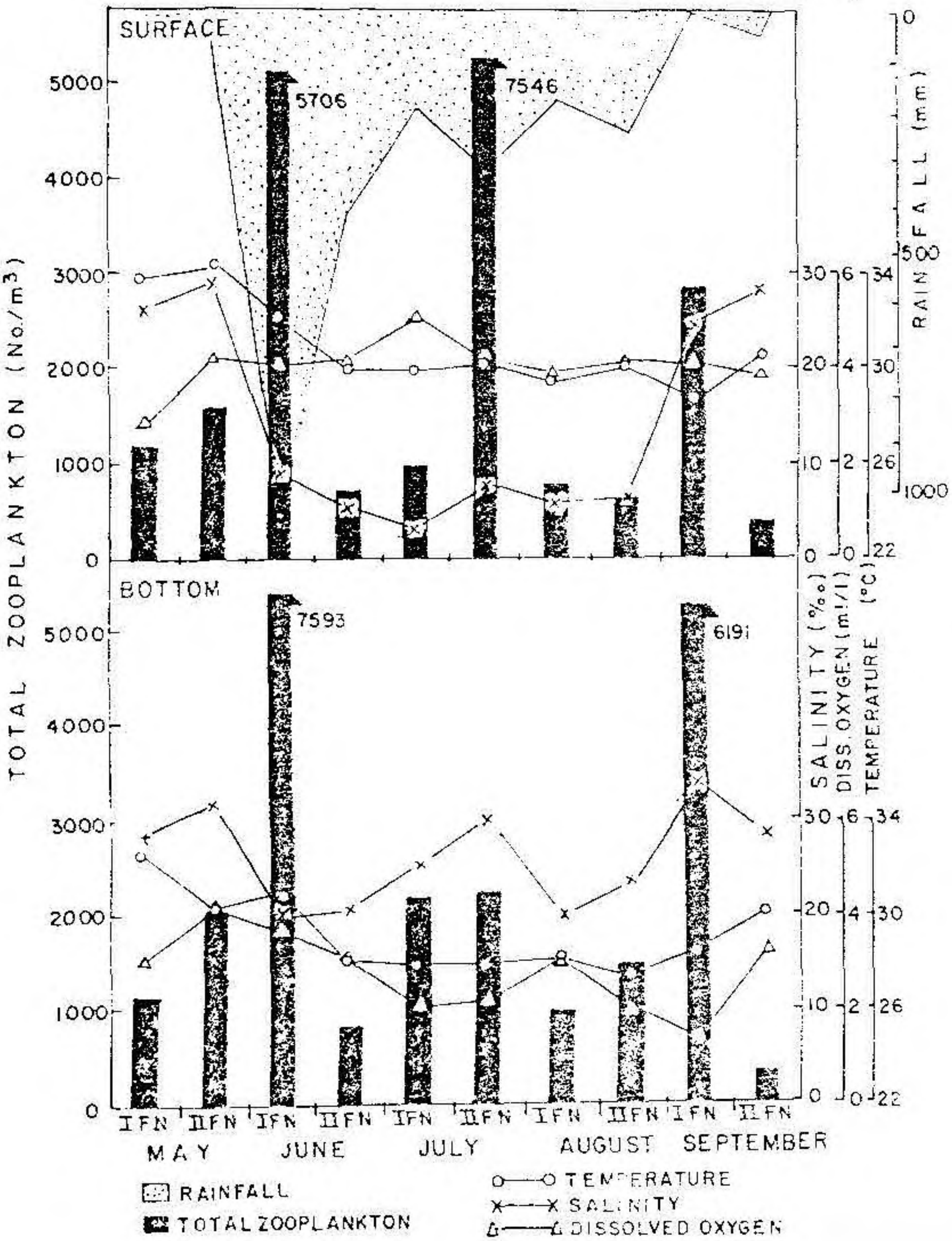


FIG. 6. FORTNIGHTLY VARIATIONS IN THE SURFACE LAYER AT STATION - 1

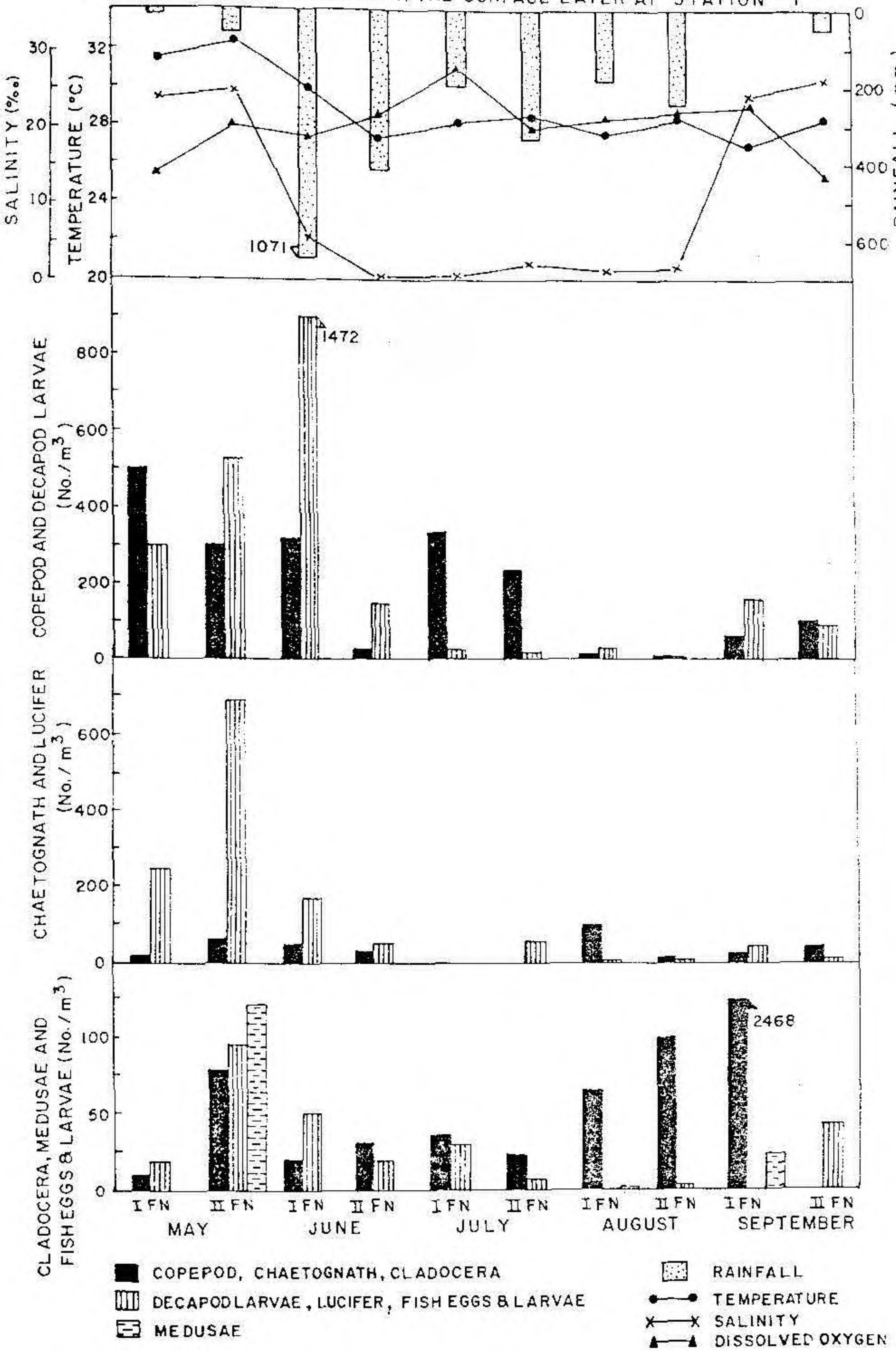


FIG. 7. FORTNIGHTLY VARIATIONS IN THE BOTTOM LAYER AT STATION - 1.

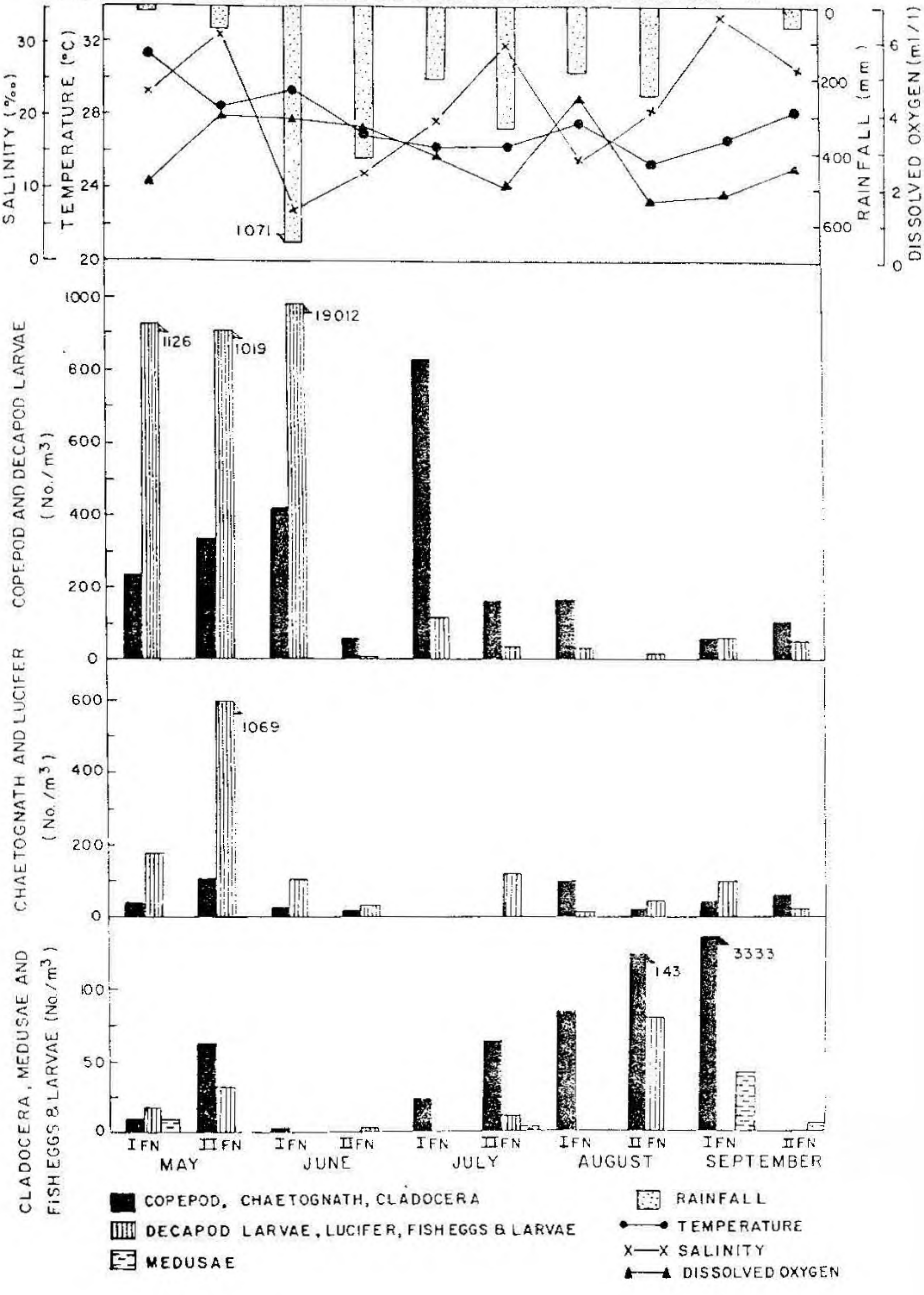


FIG. 8. FORTNIGHTLY VARIATIONS IN THE SURFACE LAYER AT STATION – 2

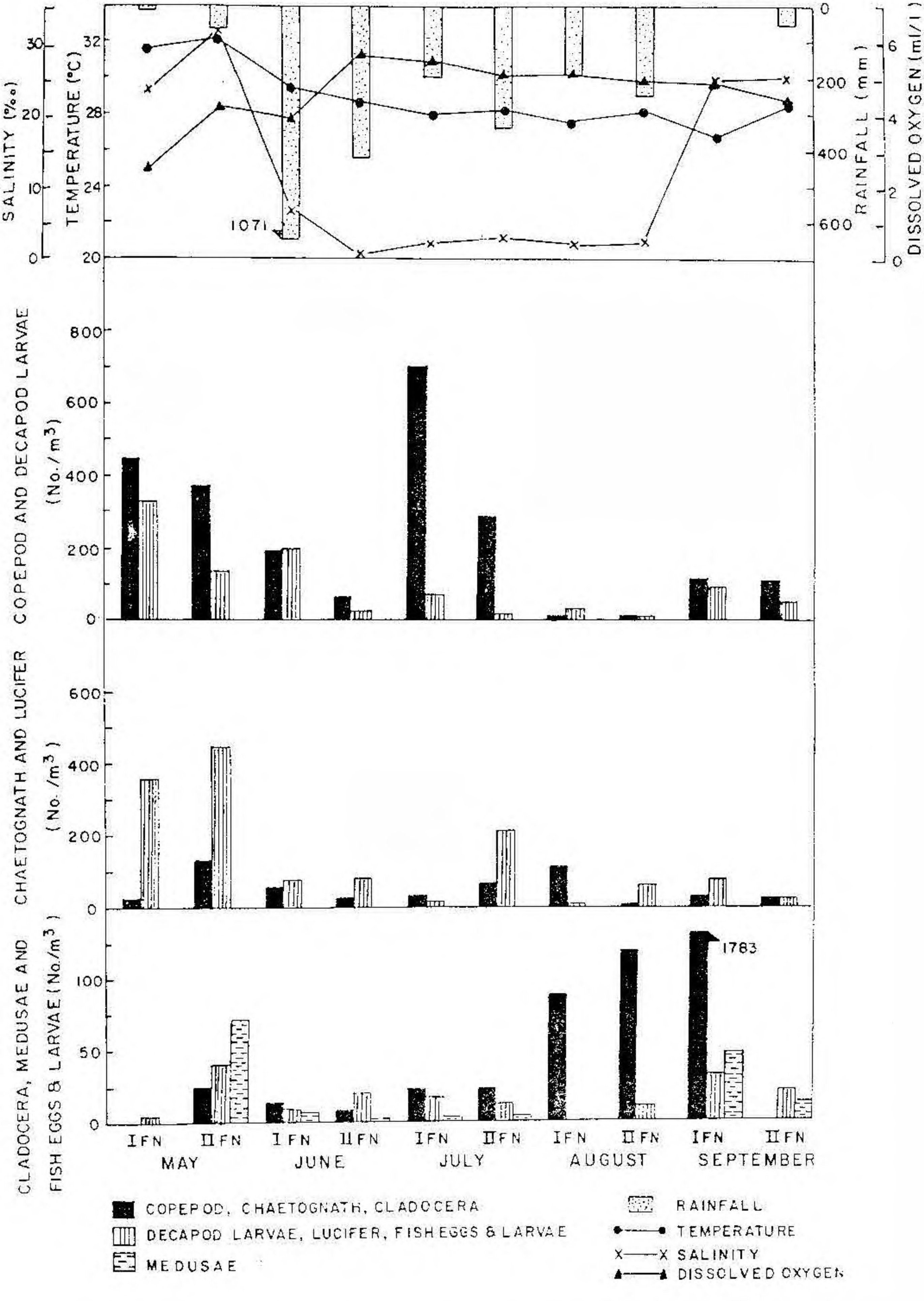


FIG. 9. FORTNIGHTLY VARIATIONS IN THE BOTTOM LAYER AT STATION - 2

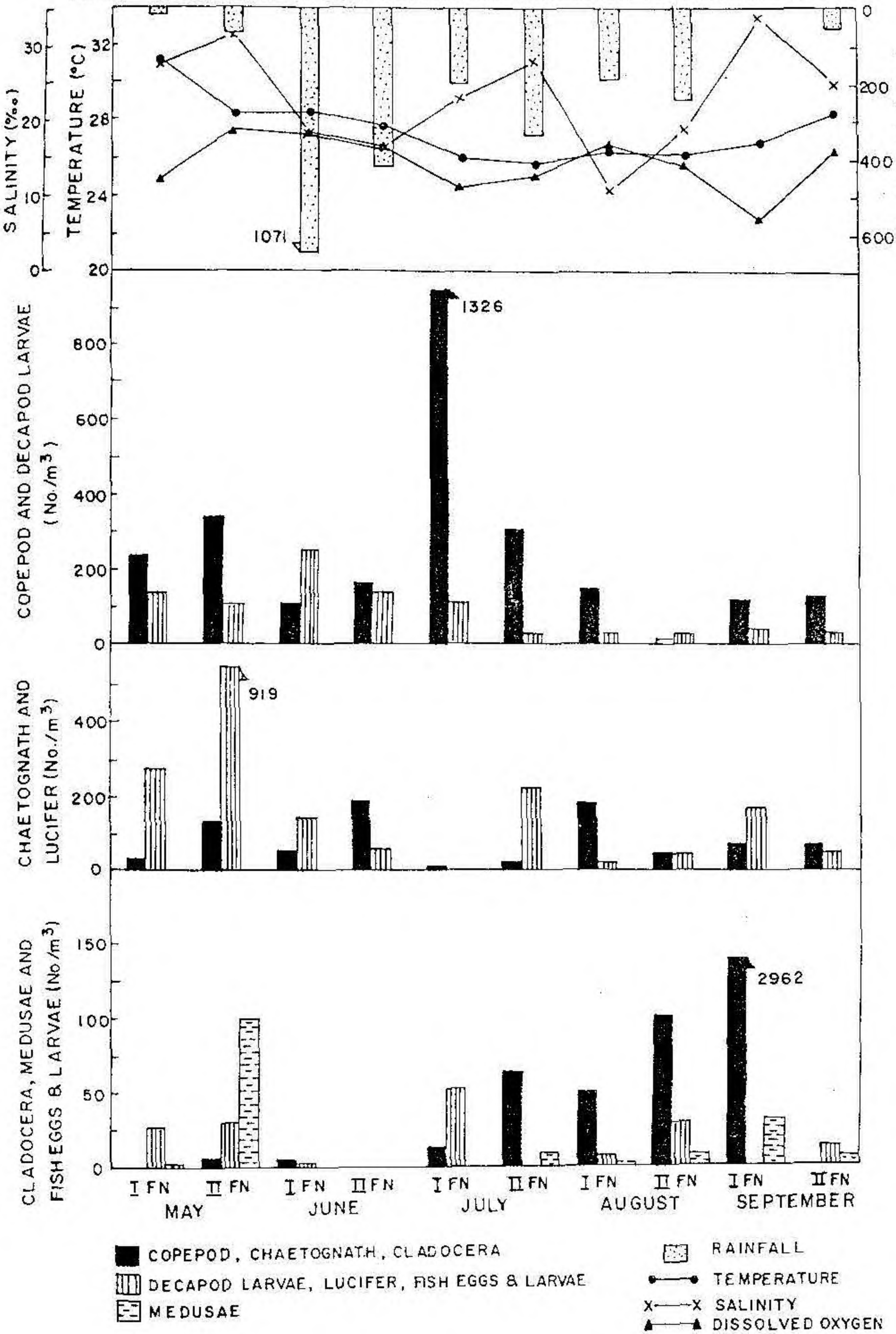


FIG.10. FORTNIGHTLY VARIATIONS IN THE SURFACE LAYER AT STATION- 3

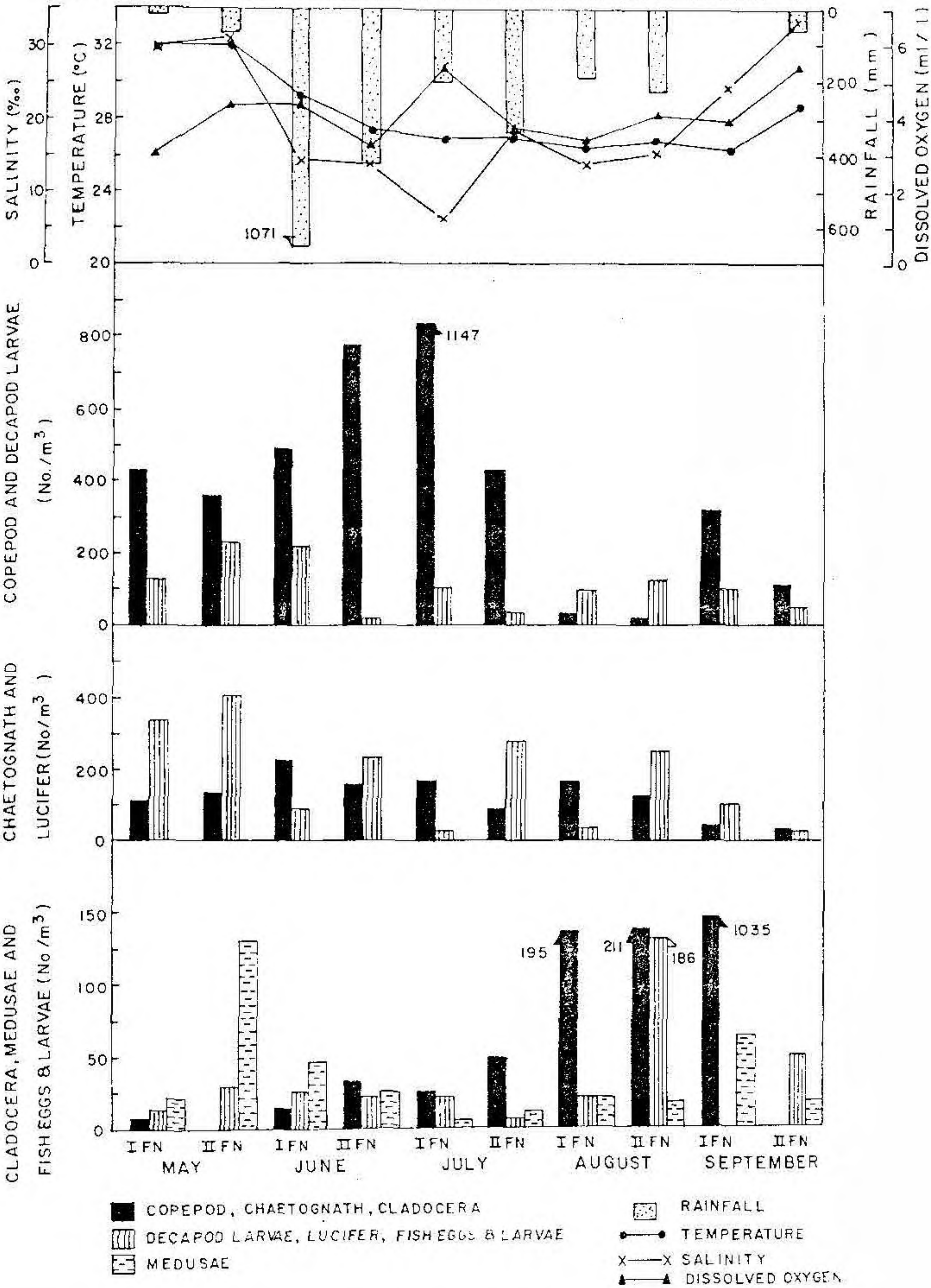


FIG. 11. FORTNIGHTLY VARIATIONS IN THE BOTTOM LAYER AT STATION - 3

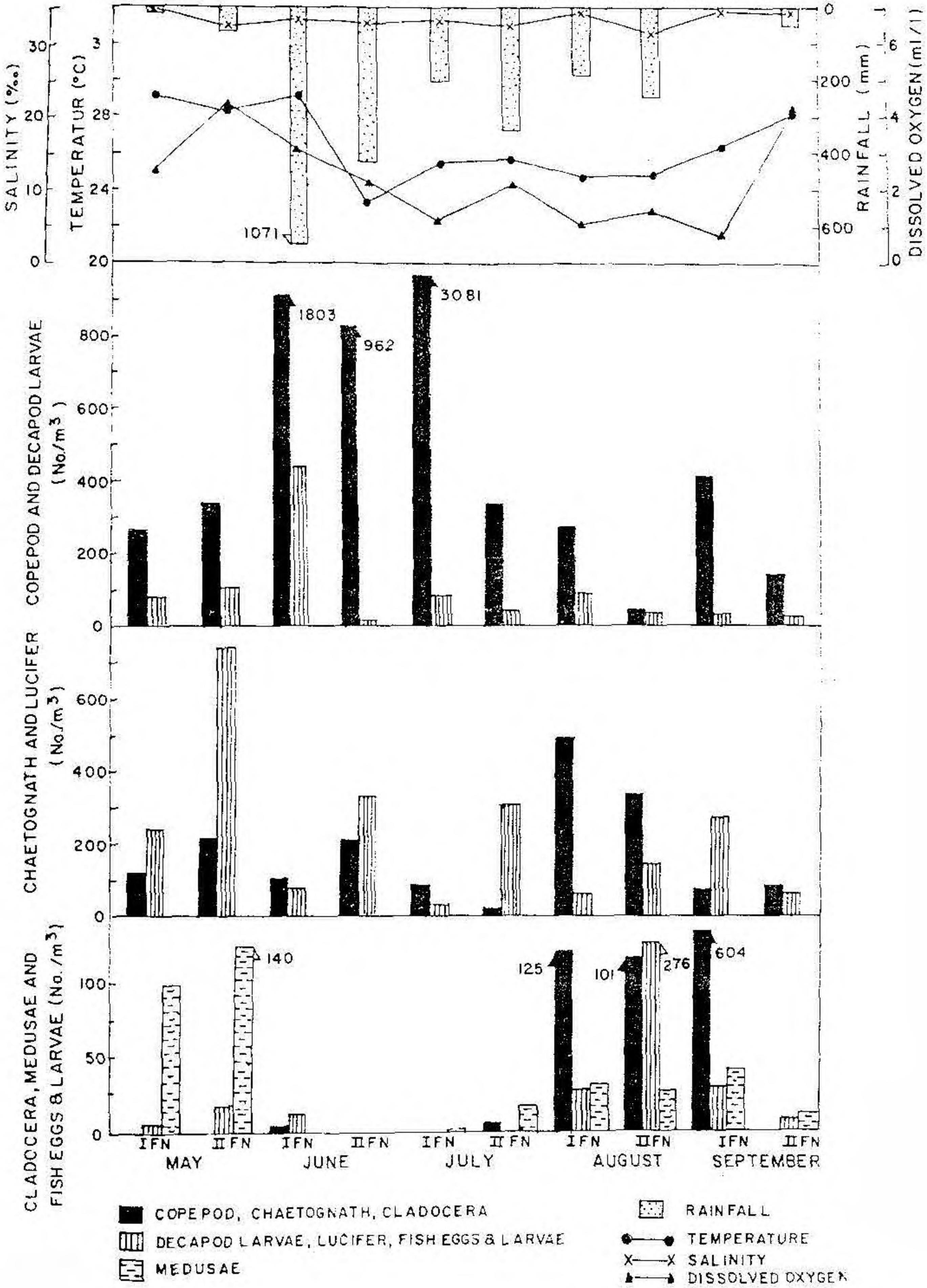


FIG. 12. FORTNIGHTLY VARIATIONS IN THE SURFACE LAYER (AVERAGE OF STATIONS 1-3)

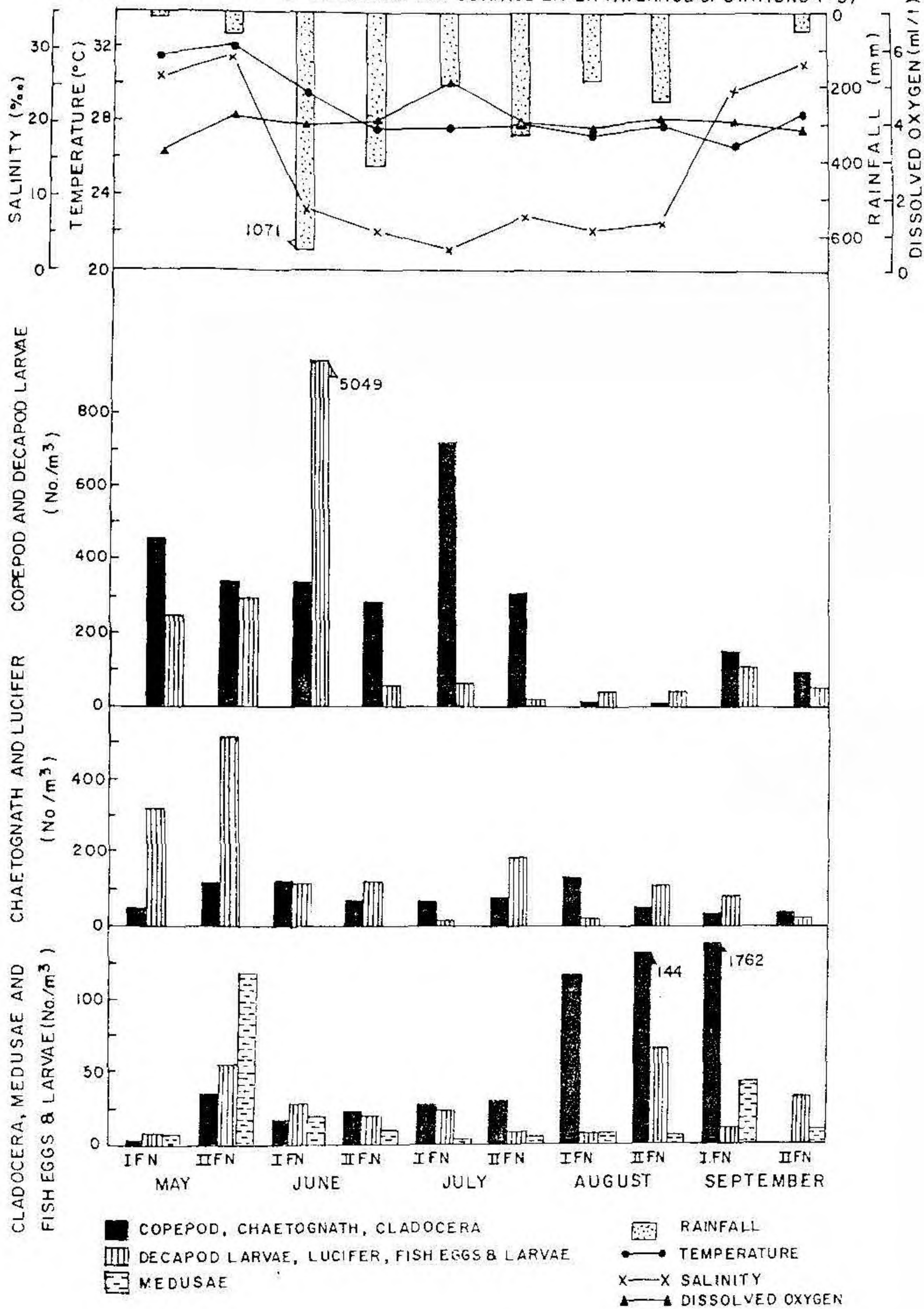


FIG. 13. FORTNIGHTLY VARIATIONS IN THE BOTTOM LAYER (AVERAGE OF STATIONS 1-3)

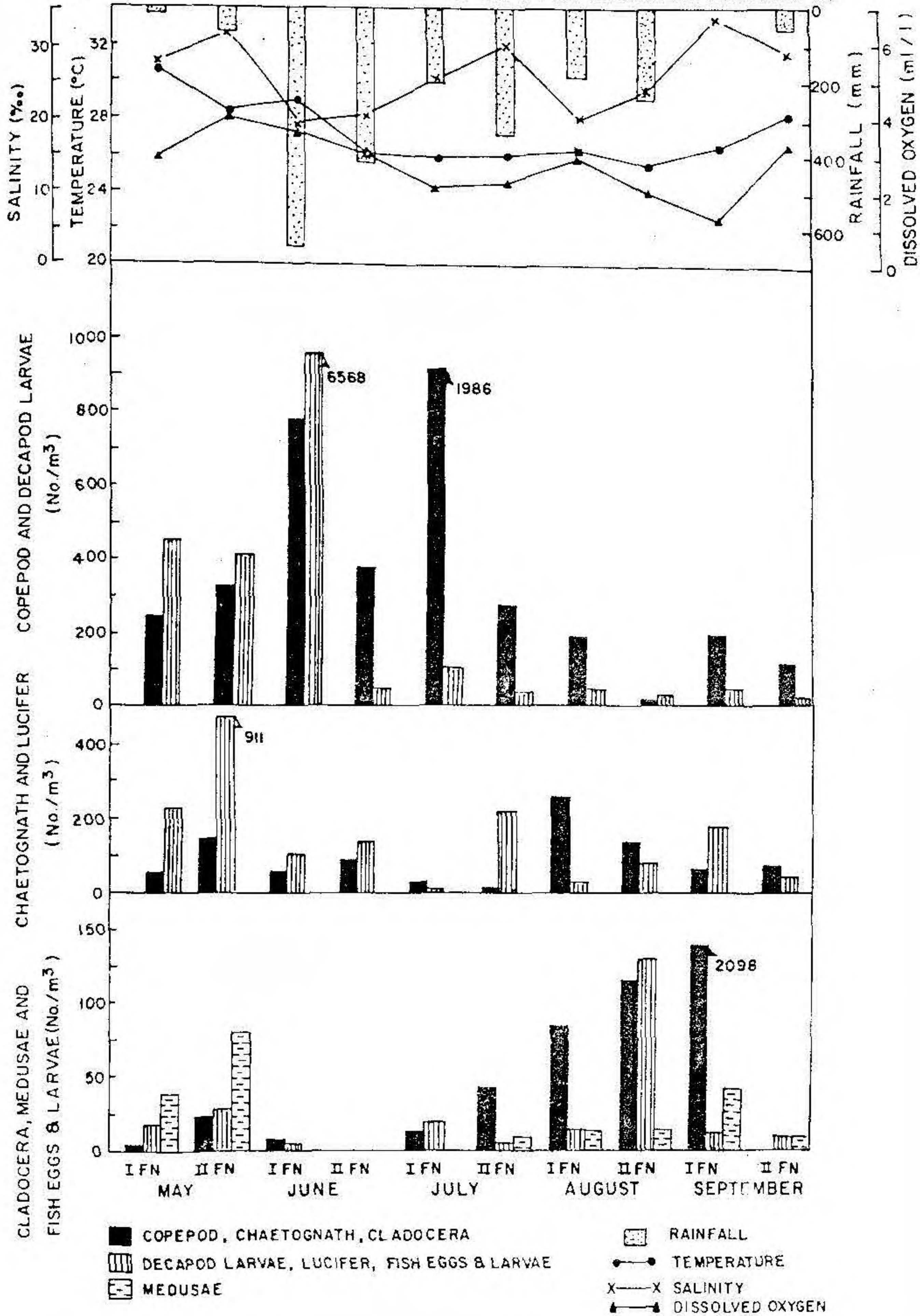


FIG. 14. MONTHLY RANGE AND MEAN OF ZOOPLANKTON GROUPS (No / m^3)

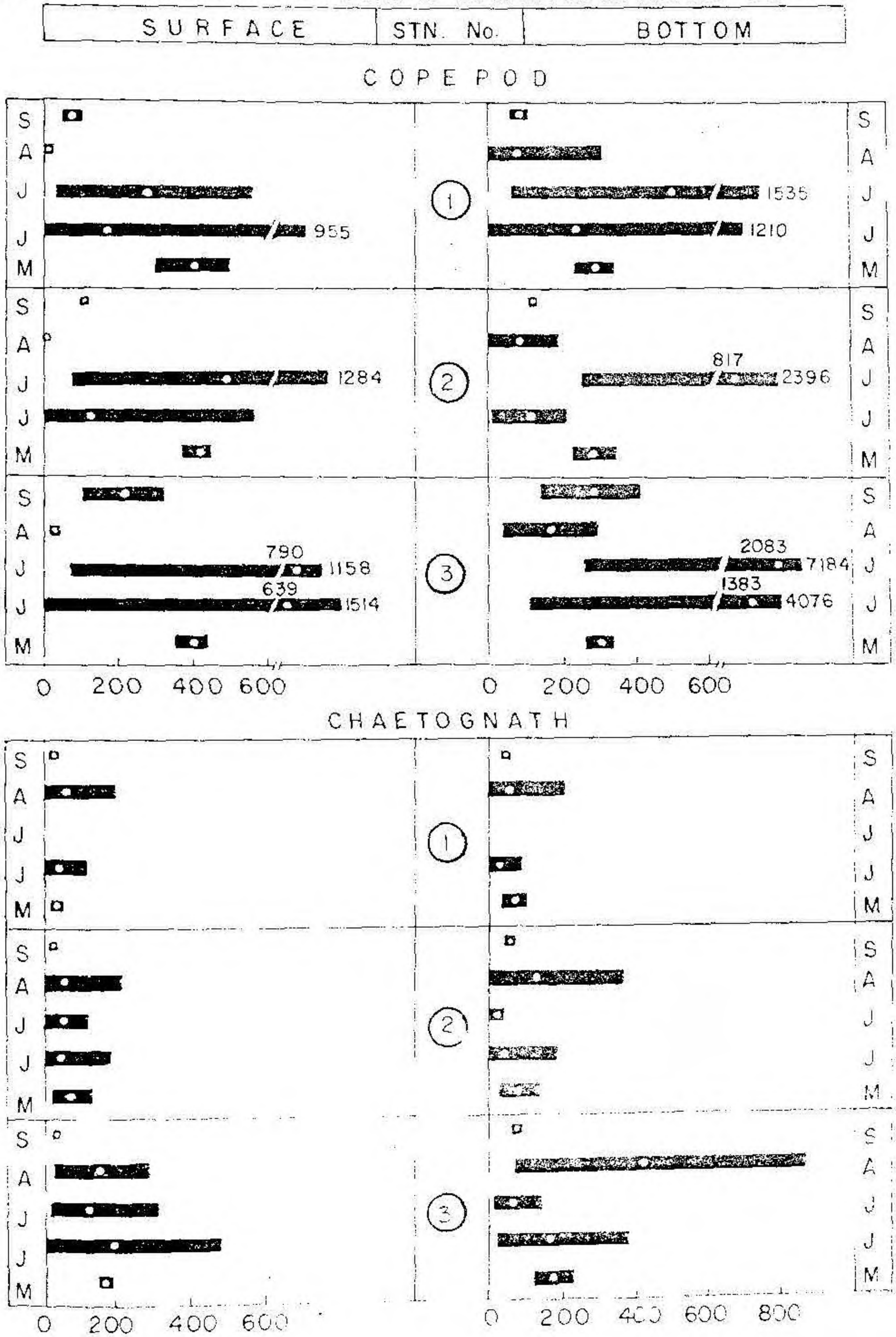


FIG. 15. MONTHLY RANGE AND MEAN OF ZOOPLANKTON GROUPS (No./m³)

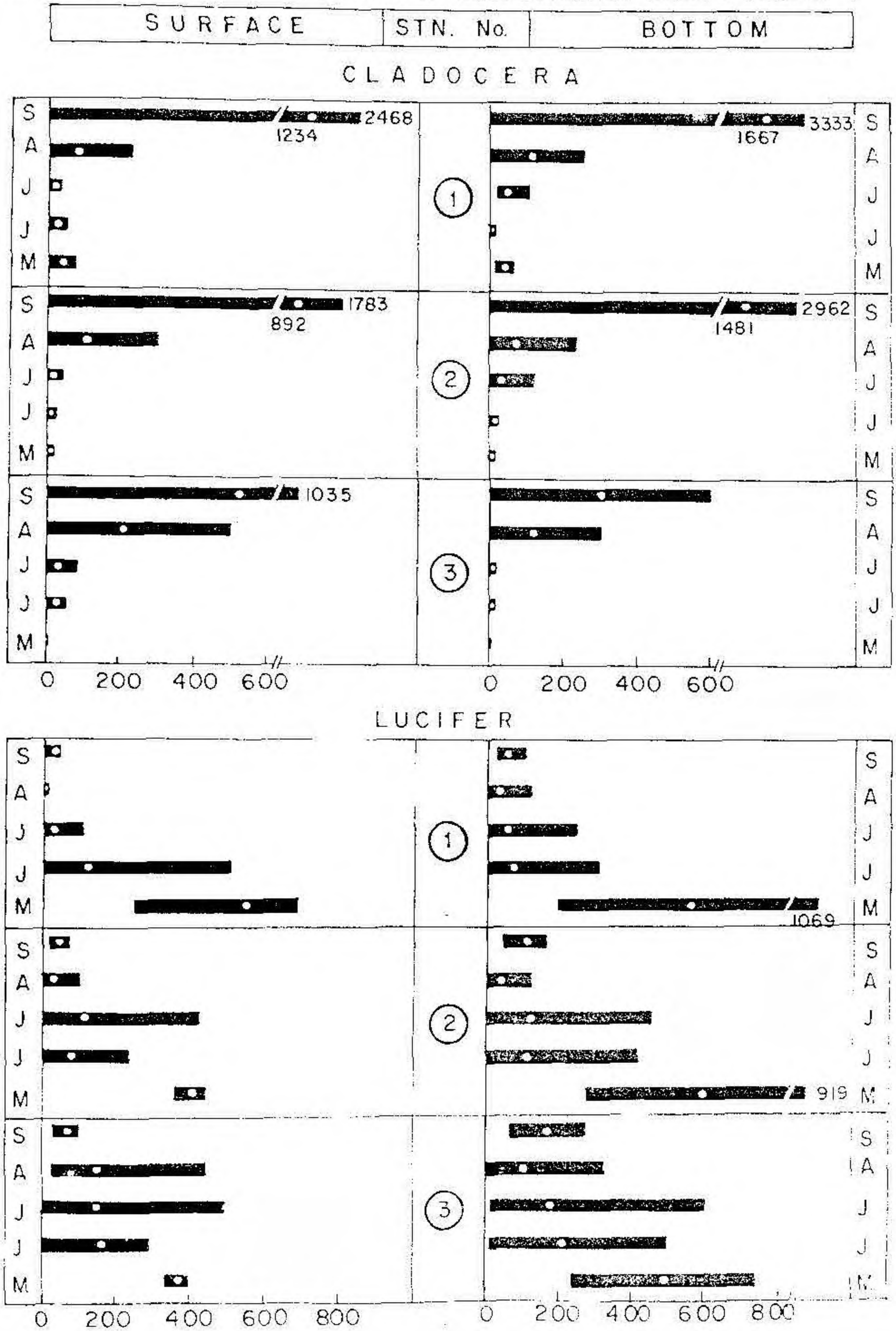


FIG. 16. MONTHLY RANGE AND MEAN OF ZOOPLANKTON GROUPS (No./m^3)

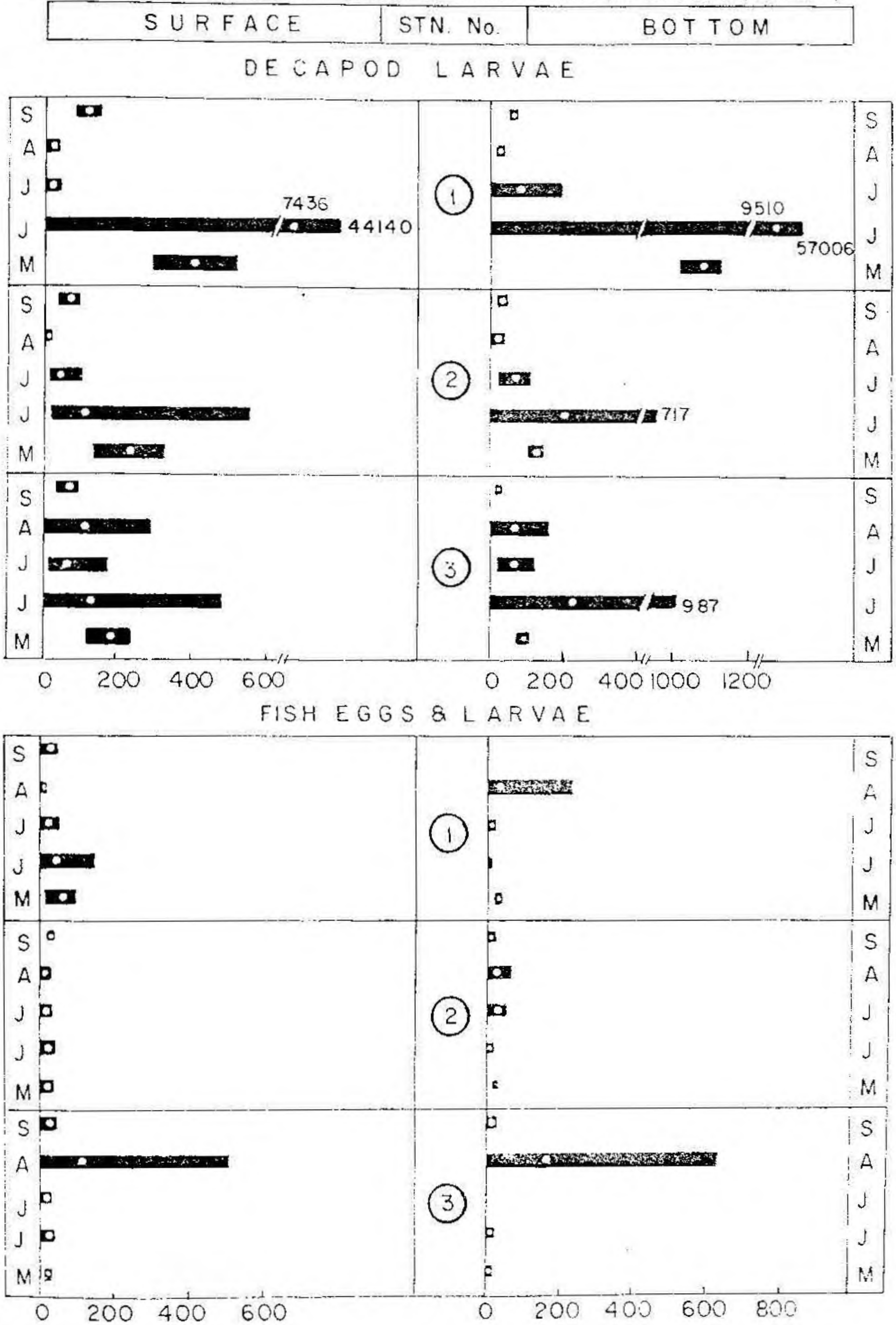


FIG. 17. CONSOLIDATED MONTHLY RANGE & MEAN OF ZOOPLANKTON IN THE STUDY AREA (No./m3)

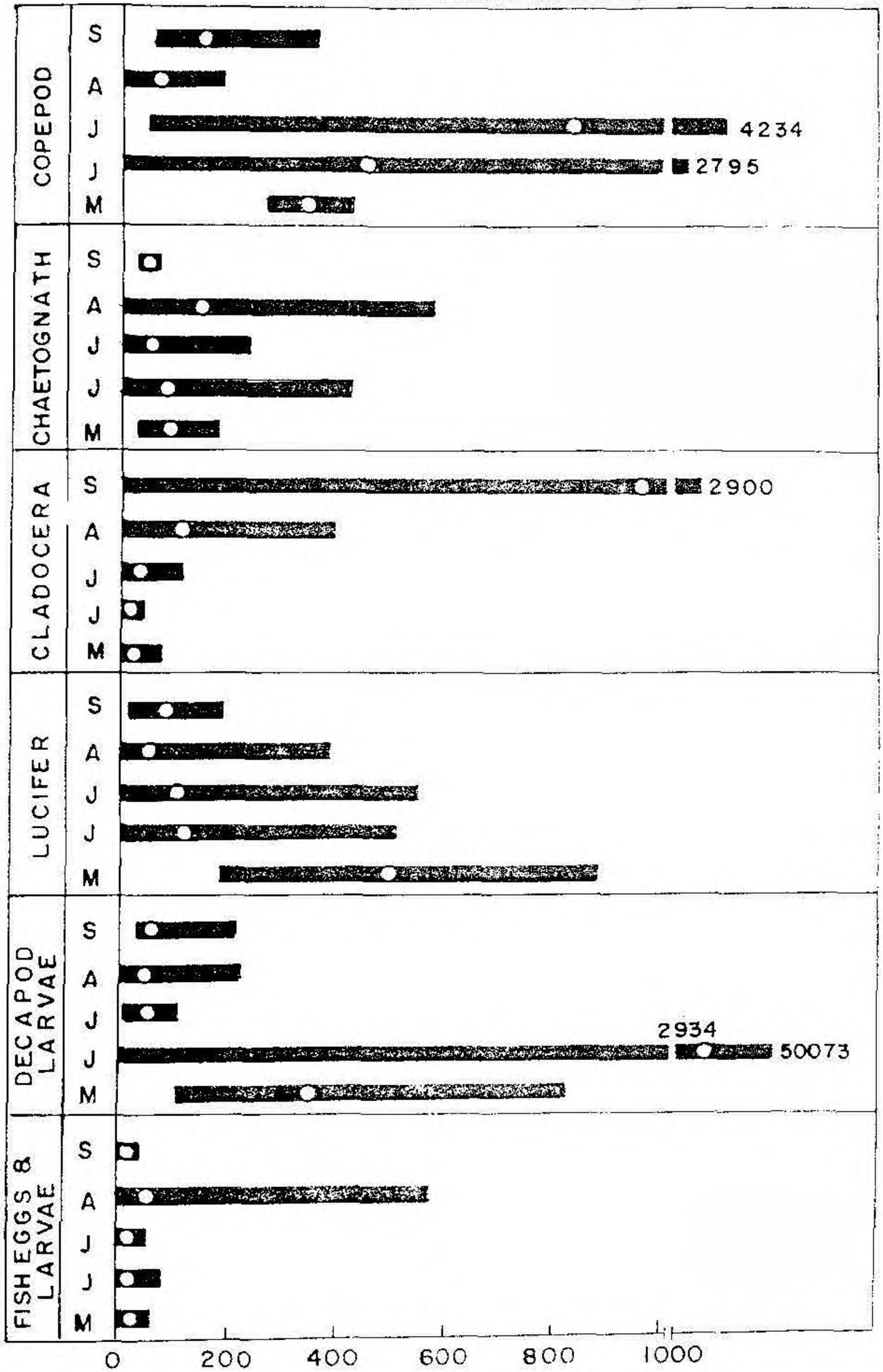


FIG. 18

FLUCTUATION IN ZOOPLANKTON ABUNDANCE IN SURFACE WATERS DURING PREMONSOON, MONSOON AND POST MONSOON MONTHS

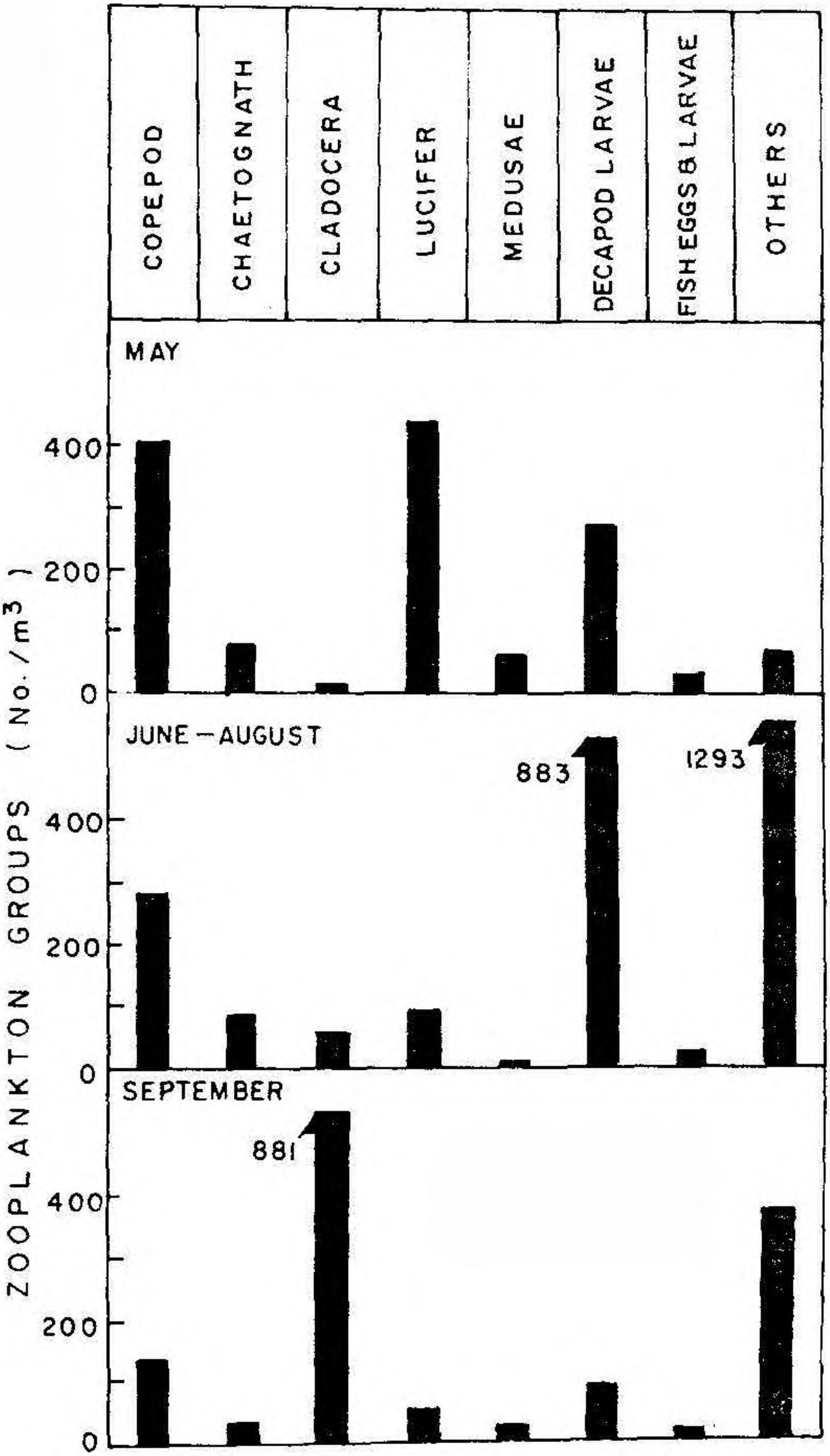


FIG.19

FLUCTUATION IN ZOOPLANKTON ABUNDANCE IN BOTTOM WATERS DURING PREMONSOON, MONSOON AND POSTMONSOON MONTHS

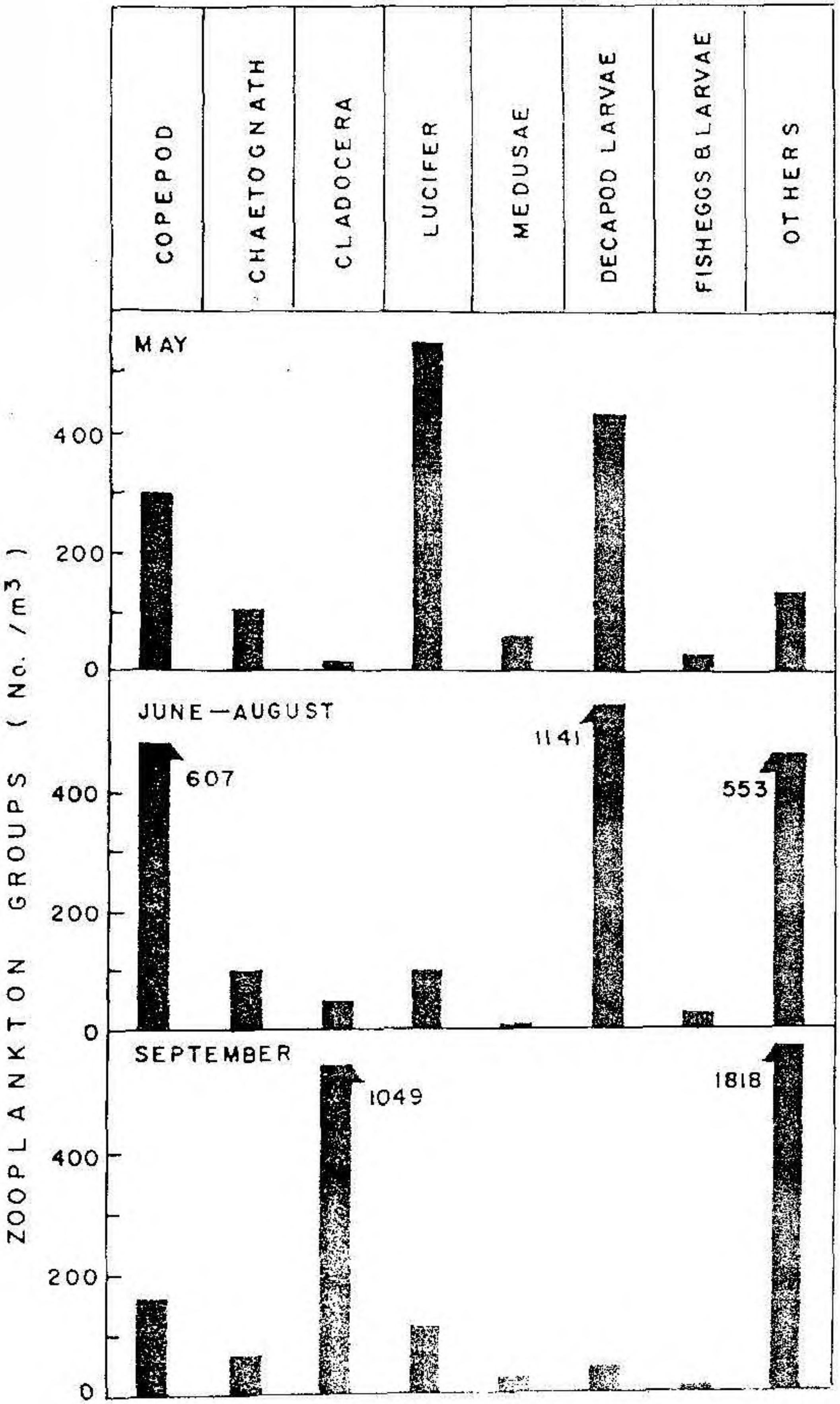


FIG. 20. MONTHLY FLUCTUATION AND RELATIVE ABUNDANCE (%) AT STATION - 1.

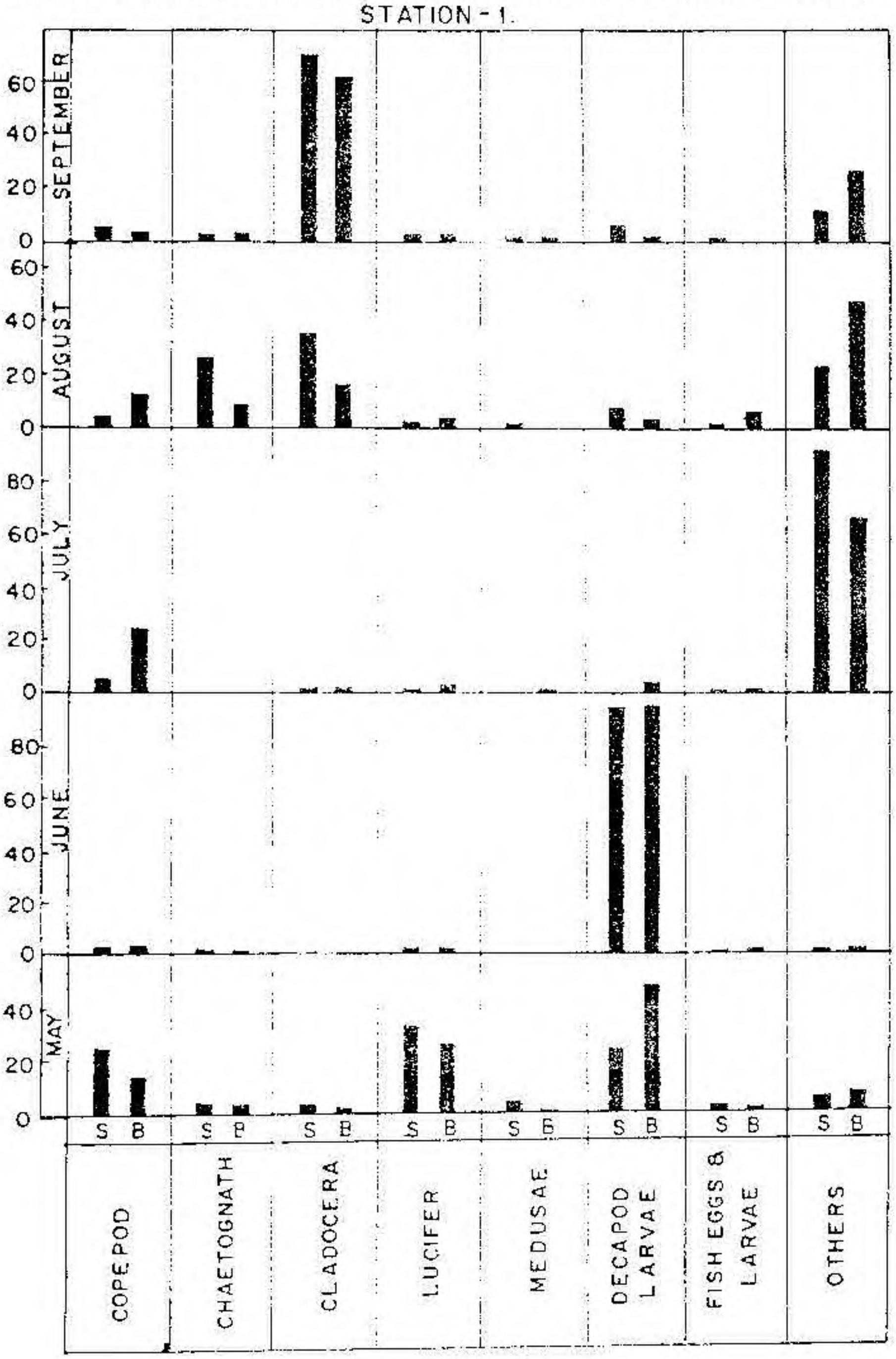


FIG. 21. MONTHLY FLUCTUATION AND RELATIVE ABUNDANCE (%) AT STATION - 2

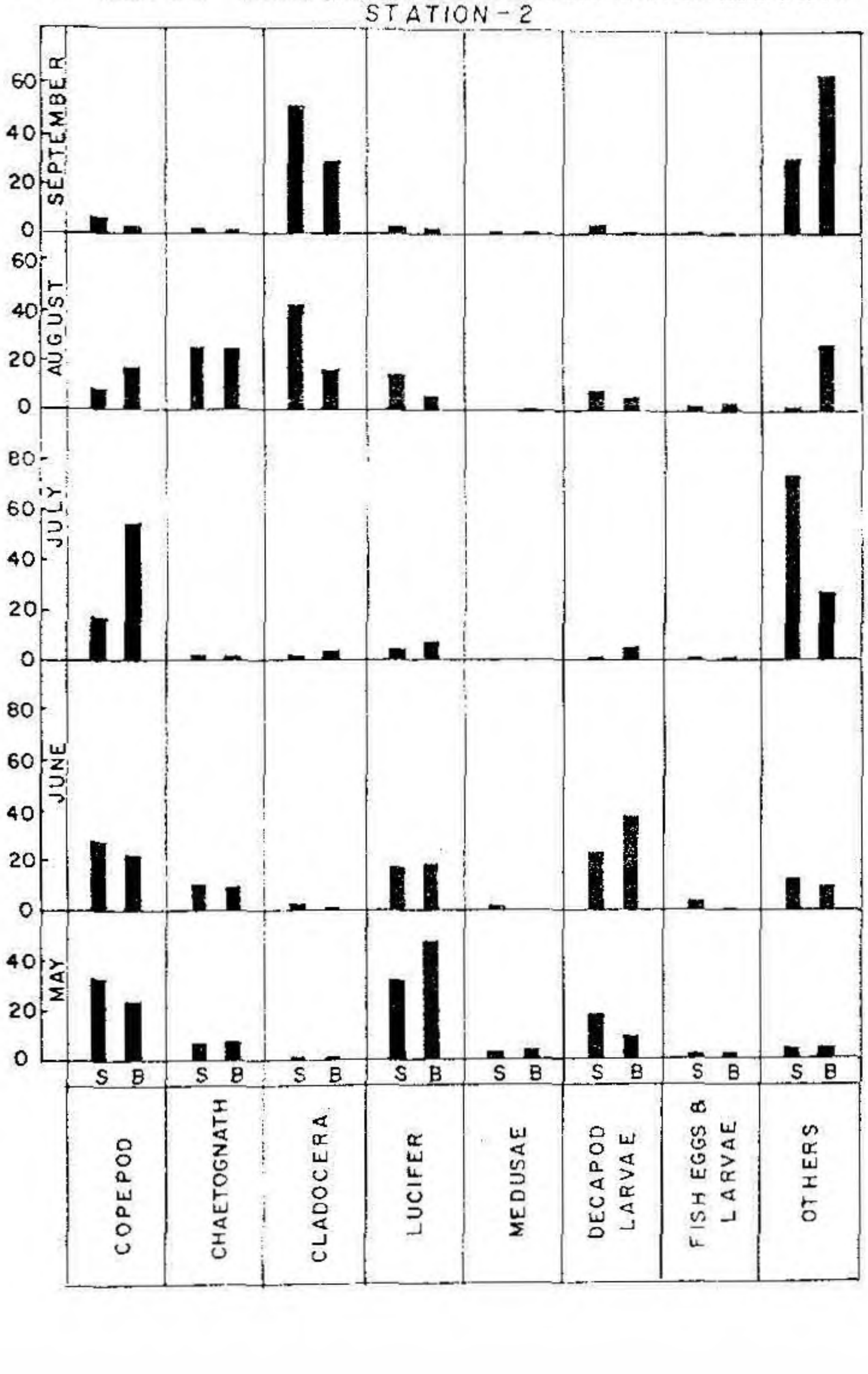


FIG.22. MONTHLY FLUCTUATION AND RELATIVE ABUNDANCE (%) AT STATION-3.

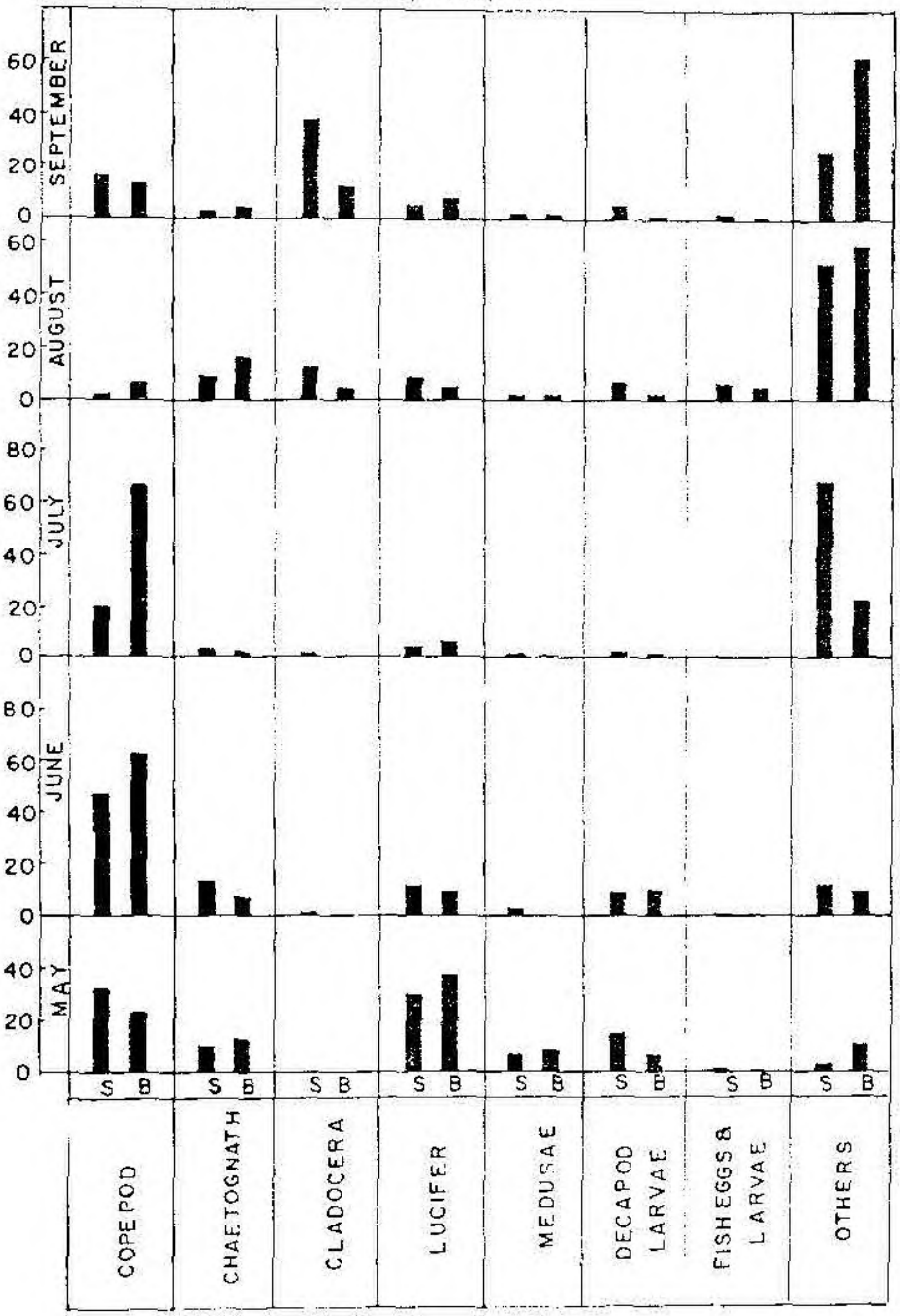


FIG. 23. MONTHLY CONSOLIDATED MEAN (AVERAGE OF 3 STATIONS)

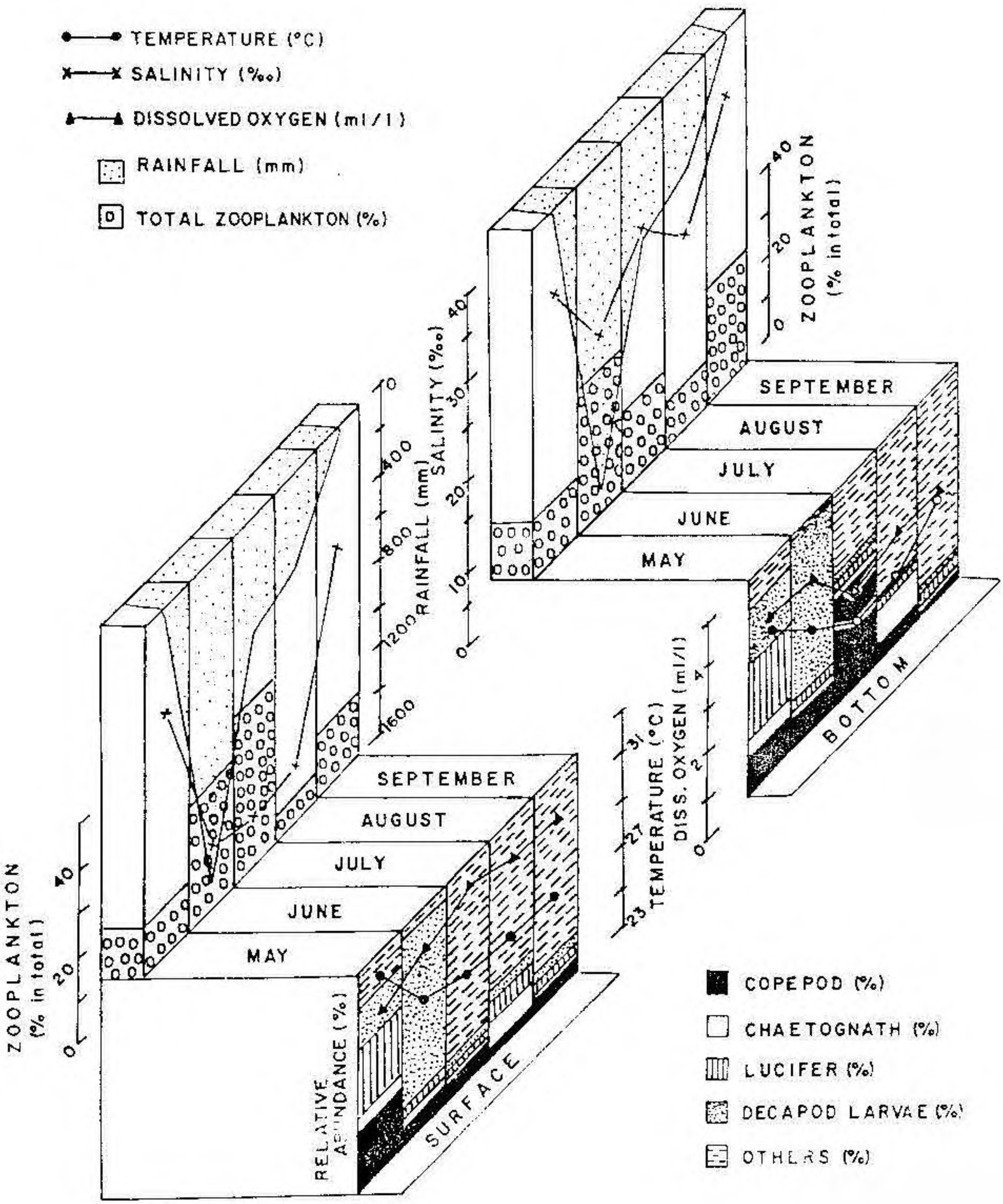
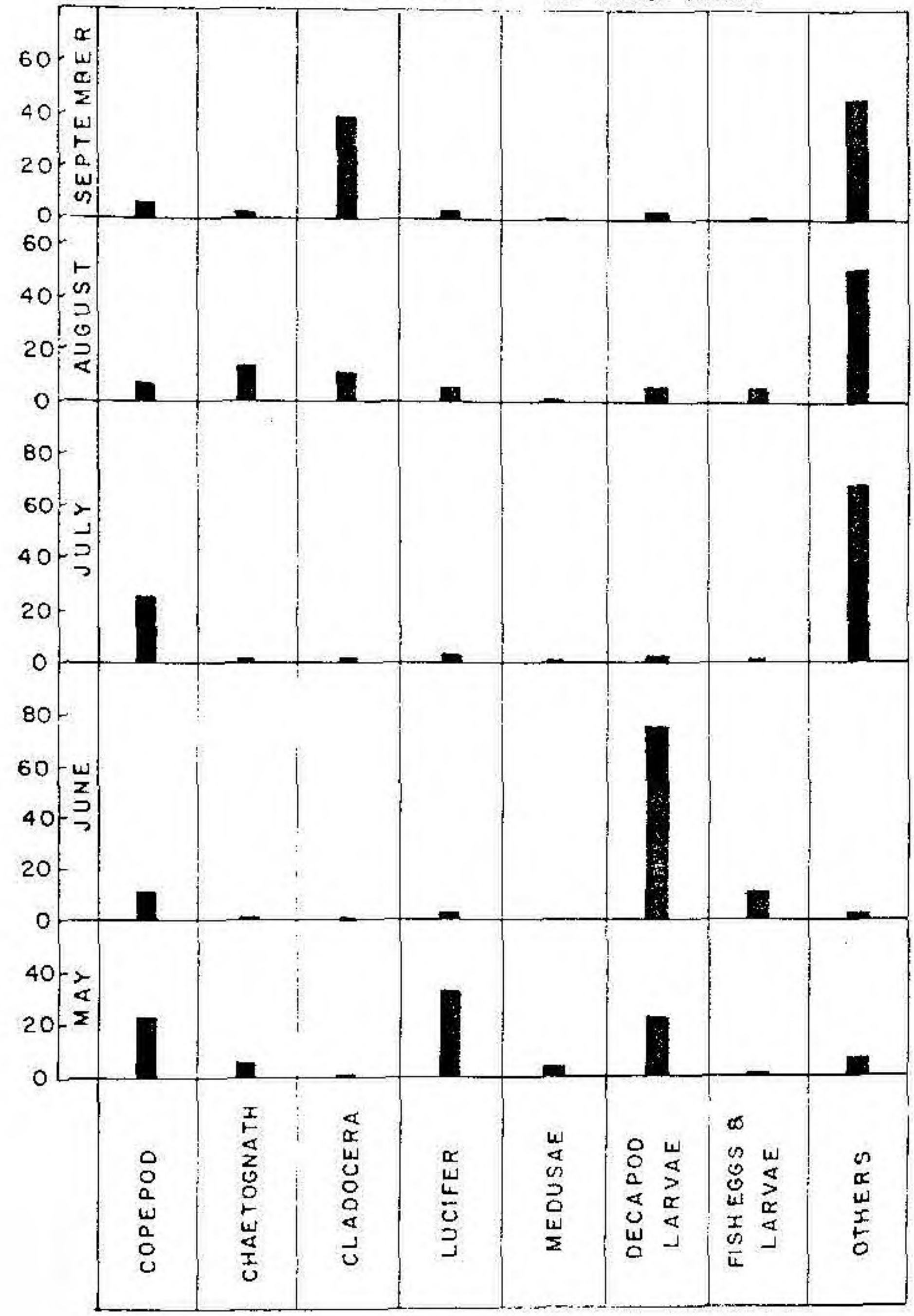


FIG. 24. MONTHLY FLUCTUATION AND RELATIVE ABUNDANCE (%) IN ENTIRE WATER COLUMN OF THE STUDY AREA



The total zooplankton showed a peak of 5706 nos/m^3 during the first fortnight of June in the study area at the surface when the fortnightly rainfall reached the maximum of 1071 mm; while another peak was recorded during the second fortnight of July with the mean density of 7546 nos/m^3 when the rainfall came down to 336 mm (Fig. 5).

These observations indicated that the regional rainfall is not directly responsible for the abundance of zooplankton in the estuarine waters during the south-west monsoon season.

The abundance of zooplankton recorded during the first fortnight of June due to the swarm of decapod larvae in the surface layer (15352 nos/m^3) and bottom layer (19695 nos/m^3) in the lesser saline zone (station-1) (Fig. 2), their mean numbers at surface and bottom in the study area (5706 and 7593 per m^3 respectively) (Fig. 5); and the overall mean values in the study area for the entire season (May-September) (2242 and 2520 nos/m^3 in the surface and bottom layers respectively) revealed that the distribution of zooplankton was relatively less in the surface column (surface to mid-depth) of the study area where the fresh-water flow was high. The diurnal mean values of total zooplankton number for the surface and bottom layers during May, June, July and September (Tables 14-17) and their averages (Table-18) at station-2 also indicated the influence of freshwater flow.

6.2. Influence of tide and coastal 'upwelling' currents

The fluctuation and abundance of dominant zooplankton groups and total zooplankton studied in relation to tidal rhythm at the middle zone (station-2) based on bihourly diurnal data during May, June, July and September are presented in Tables 14-17; and the consolidated mean values of zooplankton groups and total zooplankton per m^3 based on the four diurnal observations are given in Table-18.

During the onset of monsoon (May), the surface waters did not show much variation in total zooplankton number between low tide and high tide period, while the bottom layer showed their abundance during high tide (1C57 nos/m^3) than at low tide (363 nos/m^3). Among the groups, lucifers showed relationship with tidal rhythm; and were abundant during high tide and less during low tide period at surface and bottom waters, followed by chaetognaths (Table-14) when the salinity was relatively high at surface and bottom.

During peak monsoon months (June & July), the diurnal data showed inverse relationship with tide in the upper water column when the flood energy was more than the tidal energy at surface; while the increasing tide exercised more influence on the zooplankton abundance in the bottom layer and this increase in number was generally seen in almost all the groups except the cladocerans at the bottom (Tables-15 & 16).

Table - 14

Influence of freshwater flow and tide on zooplankton groups during May 1991 (Diurnal)

Groups	Surface (nos/m^3)		Bottom (nos/m^3)	
	Low tide	High tide	Low tide	High tide
Copepod	229	190	121	261
Chaetognath	38	56	11	75
Cladocera	8	14	10	5
Lucifer	36	159	33	344
Medusae	90	36	44	76
Decapod larvae	113	116	41	197
Fish eggs & larvae	32	24	6	14
Others	136	70	97	85
Total Zooplankton	682	665	363	1057

Table - 15

Influence of freshwater flow and tide on zooplankton groups during June 1991 (Diurnal)

Groups	Surface (nos/m^3)		Bottom (nos/m^3)	
	Low tide	High tide	Low tide	High tide
Copepod	181	150	419	872
Chaetognath	85	9	128	165
Cladocera	4	13	0	7
Lucifer	66	110	1	45
Medusae	0	0	6	0
Decapod Larvae	29	40	30	45
Fish eggs & larvae	93	41	1	5
Others	11	10	65	177
Total zoo-plankton	469	373	650	1316

Table - 16

Influence of freshwater flow and tide on zooplankton groups during July 1991 (Diurnal)

Groups	Surface (nos/m^3)		Bottom (nos/m^3)	
	Low tide	High tide	Low tide	High tide
Copepod	25	7	75	31
Chaetognath	32	1	4	161
Cladocera	12	0	32	0
Lucifer	126	102	113	310
Medusae	2	0	4	11
Decapod larvae	15	26	22	359
Fish eggs & larvae	10	3	1	59
Others	29	30	16	849
Total Zoo-plankton	251	169	267	1780

Table - 17

Influence of freshwater flow and tide on zooplankton groups during September 1991 (Diurnal)

Groups	Surface (nos/m^3)		Bottom (nos/m^3)	
	Low tide	High tide	Low tide	High tide
Copepod	494	140	616	315
Chaetognath	0	72	109	151
Cladocera	5828	3060	4772	1032
Lucifer	446	479	554	766
Medusae	1	12	108	88
Decapod larvae	324	35	191	186
Fish eggs & larvae	32	9	32	71
Others	5095	676	3582	6552
Total zoo-plankton	12220	4484	9974	9161

Table - 18

Influence of freshwater flow and tide on zooplankton groups based on average of four diurnal data (May - September 1991)

Groups	Surface (nos/m^3)		Bottom (nos/m^3)	
	Low tide	High tide	Low tide	High tide
Copepod	232	122	308	370
Chaetognath	39	35	66	138
Cladocera	1463	772	1204	261
Lucifer	169	213	175	366
Medusae	23	12	41	44
Decapod larvae	120	54	71	197
Fish eggs & larvae	42	19	10	37
Others	1318	197	940	1916
Total zoo-plankton	3406	1424	2815	3329

Towards the closure of the south-west monsoon (September), the diurnal data showed relatively high number during low tide at the surface and bottom (Table-17). This might be due to the abundance of brackishwater cladocerans in the upstream of the backwater than the number of cladocerans brought from the sea side during high tide.

However, the consolidated mean for the south-west monsoon season (average from the four diurnal data) indicated relatively low number of zooplankters at the surface and high number at the bottom layer during high tide period (Table-18).

Another factor observed during the present investigation to influence the zooplankton abundance in the bottom waters of the study area was the incursion of unusually high saline water into the backwater by the influence of coastal upwelling currents. It was observed that the total zooplankton number showed increase during the first and second fortnight of July and during the first fortnight of September in the bottom waters, characterised by the unusual increase in salinity, low temperature and very low dissolved oxygen level as recorded at stations 1, 2 and 3 (Figs. 2-4); and the same was reflected in the mean values for the study area also (Fig. 5).

6.3. Influence of temperature, salinity and dissolved oxygen

The periods of abundance of the dominant zooplankton groups in relation to temperature, salinity and dissolved oxygen are presented in Table-19.

The monthly mean values of zooplankton groups (nos/m^3) showed that lucifers and medusae were abundant in May than in any other months, when the temperature was 30.8°C and salinity was 28.74‰; decapod larvae in June when the temperature and salinity were 28.2°C and 13.62‰; copepods in July when the temperature and salinity were 27.0°C and 16.41 ‰; chaetognaths and fish eggs & larvae in August when the temperature and

Table - 19

Period of abundance of major zooplankton groups in relation to hydrographic features during May - September

Groups	Month of abundance	Temperature(°C)	Salinity (‰)	Dissolved oxygen (ml/l)
Copepod	July	26.99	16.41	3.41
Chaetognath	August	26.83	14.06	3.30
Cladocera	September	27.58	29.57	3.19
Lucifer	May	30.77	28.74	3.63
Medusae	May	30.77	28.74	3.63
Decapod larvae	June	28.21	13.62	3.73
Fish eggs & larvae	August	26.83	14.06	3.30
Total zooplankton	June	28.21	13.62	3.73

salinity were 26.8°C and 14.06 ‰; and cladocerans in September when the temperature and salinity were 27.6°C and 29.57 ‰ respectively. The total number of zooplankton was found to be more in June when the mean temperature was 28.2°C and the salinity 13.62 ‰ in the study area during the south-west monsoon season. Dissolved oxygen did not appear to influence the abundance of zooplankton in the estuarine waters during this season (Table-19).

6.4. Statistical analysis

Correlation matrix of the number of total zooplankton and groups like copepods, chaetognaths, cladocerans, lucifers, decapod larvae and fish eggs and larvae in relation to the environmental parameters like rainfall, temperature, salinity and dissolved oxygen is given for the surface waters in Table-20.

Table - 20

Statistical analysis of surface data for the study area

Correlation coefficients for total zooplankton and major groups

	Rainfall	Temperature	Salinity	Dissolved oxygen
Total zooplankton	-0.3709*	0.3121*	0.7106*	-0.2287
Copepod	-0.3001*	0.3300*	0.4648*	-0.1715
Chaetognath	0.0007	0.2829	0.1443	-0.2800
Cladocera	-0.2652	-0.3459*	0.2926	0.1173
Lucifer	-0.2809	0.3647*	0.6205*	-0.2024
Decapod larvae	-0.2299	0.2707*	0.6520*	-0.1487
Fish eggs & larvae	-0.2342	0.3046	0.3277*	-0.0261

* Significant at 5% level

Total zooplankton number in the surface waters showed significant positive correlation with temperature and salinity and negative correlation with rainfall. Among the zooplankton groups, copepods, lucifers and decapod larvae showed significant positive correlation with temperature and salinity; while the fish eggs and larvae showed significant positive correlation with salinity only; cladocera showed significant negative correlation with temperature.

Correlation of surface and bottom zooplankton with tidal amplitude was found to be negative and insignificant ($r = -0.112247$ and -0.084197 respectively) at 5% error for 26 degrees of freedom.

Analysis of variance showed no significant difference in total zooplankton counts among the stations as well as between surface and bottom layers ($F = 1.650$, 0.033 and 0.006 for 2, 1 and 2 degrees of freedom for 102 error).

D I S C U S S I O N

Fair knowledge on the environmental factors of the study area is an essential prerequisite in the investigation of fluctuation and abundance of any biological community.

The south-west monsoon season along the south-west coast of India is associated with sudden changes from marine to brackishwater condition in the coastal ecosystems. During this season, significant changes occur in the environmental features of the estuary. The topography of the estuary, tidal currents, freshwater discharge and water circulation are the master factors that play important role in making these estuarine waters a highly complex environment. These master factors are responsible for the distribution of temperature, salinity, dissolved oxygen and other chemical components in the estuary; and these, in turn, govern the distribution of organisms present in the ecosystem.

The annual average rainfall of Cochin region is estimated as 3230 mm (Daily Weather Chart), of which 75% occurs normally during the south-west monsoon (Sankaranarayanan and Qasim, 1969). The monthly rainfall data of 1991 for Cochin region indicated the onset of south-west monsoon in May and its closure in September. The total rainfall recorded for this season was 2600 mm constituting more than 80% of the annual mean. This indicated very good rainfall during the south-west monsoon season in 1991. The data showed that the onset (May), peak (June-August) and closure (September) of monsoon contributed 3%, 95% and 2% of rainfall respectively. The highest rainfall of 1071 mm in the first fortnight of June, followed by the other relatively high values (245-420 mm) recorded during the second fortnight of June, second fortnight of July and second fortnight of August and the intermittent low values observed in the first fortnight of July (205 mm) and first fortnight of August (185 mm) seemed to have direct or indirect influence on the hydrographic parameters and zooplankton fluctuation.

With regard to temperature, reduction in water temperature was noticed in the surface layer during the peak monsoon months by the influence of freshwater flow. The very low temperature ($< 26°C$) recorded occasionally at the bottom waters during June-September showed some relationship with the simultaneous reduction in dissolved oxygen and increase in salinity values especially in the backwater stations.

The sharp decline in salinity leading to almost freshwater condition from May to June and the low values observed during the peak monsoon months especially in the surface layer of the backwater stations (1 & 2) than at the Fairway buoy station (No. 3) indicated the influence of rainfall and freshwater discharge in the backwater and the relatively high values observed at station-3 might be attributed to the influence of coastal currents, mixing processes and upwelling effect of this season. During the peak monsoon months, the salinity values at the surface and bottom layers indicated vertical gradients at stations 2 & 3 with the low value at the surface, indicating the influence of freshwater flow at surface and tidal flow in the bottom layer.

The results revealed that the dissolved oxygen values were generally high at the surface layer during the peak monsoon months at all stations. This increase might be attributed to the freshwater discharge and primary productivity. Qasim *et al.* (1969) and Haridas *et al.* (1973) have also recorded such high values in the estuarine region during south-west monsoon season.

The results indicated that the bottom waters occasionally registered unusually low values of temperature and dissolved oxygen and high salinity values during June-September which are characteristic features of the offshore bottom waters. The unusual increase in the bottom salinity during the third week of June (25.80 ‰), first week of July (33.43 ‰), third week of July (32.33 ‰), third week of August (30.31 ‰) and first week of September (34.19 ‰) with intermittent low values observed in the other weeks at the middle zone (station-2) (Table-4) in relation to relatively low dissolved oxygen level and low temperature (in general); and the occurrence of the same trend in a lesser magnitude at station-1 indicated the influence of coastal currents related to 'upwelling' in the inshore and backwaters.

To check whether these high values of salinity in the backwater are due to the influence of high tide (tidal rhythm) during this season, the bihourly diurnal data on salinity obtained at station-2 (middle zone) on a 'normal day' in the fourth week of June and July were examined (Table-3). The diurnal data revealed that the salinity at the highest tide never exceeded 16.75 ‰ in the fourth week of June and 24.0 ‰ in the fourth week of July while the salinity recorded in the third week of June and July (previous week) were 25.8 ‰ and 32.33 ‰ respectively. (Ref. Figs. 7 & 9 also for fortnightly representations at station 1 & 2 respectively); whereas the bihourly diurnal data obtained on an 'upwelling' day (7-9-1991) in the first fortnight of September showed the highest salinity value of 34.64 ‰ during high tide with very low oxygen ($<$1.0 ml/l) at station-2 while in the next fortnight the salinity value came down to 25.33 ‰ with relatively high oxygen level (Table-4 and Fig. 9). It was clear from the values of the previous and succeeding weeks that the incursion of the very high saline water into the backwater was not a continuous process and the intensity of these coastal currents varied from time-to-time and it might become weak or absent even within the fortnight itself and might start again during this season. Ramamirtham and Jayaraman (1963); Shynamma and Balakrishnan (1976) and others have reported the incursion of upwelled water into the Cochin backwater during the south-west monsoon season.

However, the present investigation confirms the intrusion of colder high saline offshore bottom water into the higher saline zone (Station-3) and their influence into the backwater along the elevated bottom topography without affecting the hydrographic features of the surface layer much during June-September. The incursion of high saline water into the backwater from the sea alongwith other physico-chemical and biological properties may have profound influence on the zooplankton fluctuation and abundance within this estuarine ecosystem.

During the south-west monsoon period, the effects of three sub-seasons viz. the premonsoon effect in May, the peak monsoon effect in June-August and the postmonsoon effect in September are recognised in the backwater based on the general hydrographic conditions. By the onset of monsoon, the marine species present in the backwater (during summer) become inactive, die and are added to detritus and are gradually replaced by the multiplication of brackishwater and freshwater species. These forms appear in large numbers during the peak monsoon and they get disappeared by death and decay when the freshwater discharge is reduced and the salinity of water increased towards the closure of the monsoon season. Silas and Pillai (1975) and Rao (1977) also have reported similar trends.

Consequently the results revealed the presence of three modes of zooplankton population during May-September. The initial mode observed during the beginning of the monsoon (May) was of lesser concentration when compared to the next two modes observed during peak monsoon and postmonsoon in the study area as a whole. These modes were much pronounced in the surface layer than in the bottom waters.

These modes showed variations in their magnitude from station to station during the period of investigation. The initial peak observed at station-1 in surface and bottom layers was dominated by the outburst of decapod larvae (brachyuran zoea) recorded on 1-6-1991 (first fortnight of June). Menon et al. (1975) have recorded gradual increase of decapod larvae from May to July with peak recorded in July. The early occurrence of the swarm in the present investigation might be due to the early onset of monsoon, as the swarm was found to be influenced much by the onset of south-west monsoon with increase in freshwater flow and gradual reduction in salinity. This mode disappeared in the next fortnight from the study area when the salinity came down below 5 ‰ in the surface as the result of heavy rainfall. This trend was felt at station-2 also (Figs. 2 & 3). The decline in the second fortnight of June at stations 1 & 2 indicated heavy mortality of zooplankters. It was confirmed in the field observation by the record of dead zooplankters in the surface water between stations 1 & 2 during the second and third week of June. Menon et al. (1971); Haridas et al. (1973); and Madhupratap and Haridas (1975) have also reported about the reduction in the zooplankton with heavy rainfall and lowering of salinity. Another set of species of zooplankton groups was found to replace the above ones (succession) in the first fortnight of July at stations 1 & 2 while station-3 did not show such decline in the total zooplankton number, indicating the continuous sustenance of the zooplankton groups at this zone (Fig. 4).

The relatively low density of zooplankton number observed in the surface and bottom waters at station-2 (middle zone) than at station-1 (lesser saline zone) and at station-3 (higher saline zone) indicate high mortality rate of the zooplankton communities at the middle zone by the mixing up of the low and high saline waters from the other two zones by the tidal and freshwater flow especially with more freshwater influence as evidenced from the salinity values of stations 1, 2 and 3 (Figs. 2-4). This is in accordance with the observations of Silas and Pillai (1975) who have stated that low saline waters will have detrimental effect on the marine species.

The abundance of total zooplankton number by the occurrence of the dense blooming of the dinoflagellate, *Noctiluca* especially in the surface waters (21765 nos/m^3) of the lesser saline zone (station-1) during the second fortnight of July in the peak monsoon season contradicts the remarks stated by Mathew *et al*. (1988) that "*Noctiluca* appears in blooms during the post-monsoon and premonsoon seasons" based on the earlier records. The simultaneous abundance observed at the middle and higher saline zones (though in relatively lesser concentrations); and the very low concentration recorded in the previous two fortnights at station-1 as indicated in the total zooplankton number (Fig. 2) reveal that its occurrence at station-3 (Fig. 4) might be responsible for its dispersal into the lesser salinity zone (in the backwater) by the influence of tide and coastal 'upwelling' currents, where it could flourish well, probably by the interaction of freshwater discharge and the saline water; and the availability of more nutrients at this zone, as observed by Preetha Paul during June-July (1990).

The unusual rise in the bottom salinity by the incursion of offshore waters towards the coast during the first and second fortnight of July (peak monsoon) by the influence of coastal upwelling process might have influence on the increase in zooplankton in the bottom layer during the first and second fortnight of July at stations 1-3 (Figs. 2-4). The sudden depletion of the peak observed in the first and second fortnight of August at stations 1 & 2 without any remarkable fluctuations in the temperature, salinity and dissolved oxygen in the surface layer might be attributed to some other unfavourable environmental factor or factors prevailed during August in the lesser saline zone. Another increase in the zooplankton number observed during the first fortnight of September in the surface and bottom waters at these three zones might be due to the reduction of freshwater flow and influence of coastal upwelling and tidal effects as evidenced from the increase in salinity values which is more pronounced in the bottom waters.

Considering the fortnightly mean of total zooplankton number, the fluctuation was considerably more at stations 1 and 2 in the surface and bottom water columns than at station-3 (Figs. 2-4).

Copepods play a vital role among the zooplankton communities in the freshwater, estuarine and marine ecosystems. Their peak at station-1 during the first fortnight of May, disappearance in the second fortnight of June, reoccurrence during the first and second fortnight of July, decline in the second fortnight of August and their appearance again in September in the surface and bottom waters indicate the succession of species of different salinity tolerance at station-1 (Figs. 6 & 7). Silas and Pillai (1975) also observed species succession in copepods with changes in salinity during this season.

Station-2 also reflected the same trend especially in the surface layer whereas in the bottom layer, the sharp decline was not clear between the first and second set of community during the second fortnight of June although a declining trend could be seen during June (Figs. 8 & 9). It was due to the influence of the copepods from the higher saline zone (station-3) by tidal effect, leading to the peak in the first fortnight of July at surface and bottom; while the decline between the second and third set of species of copepods was clearly indicated in August in the bottom waters (Fig. 10 & 11).

In the surface layer of the backwater station (1 & 2), the first set of copepod community observed during the onset of monsoon (May) showed declining trend with decrease in salinity from about 30 ‰ to 5 ‰. The second set of copepods by succession flourished well in very low salinity of less than 5 ‰; while the third set of copepods survived in the salinity of more than 20 ‰ (Figs. 6 & 8). The bottom layer of the backwater stations seemed to show some relation in the copepod abundance corresponding to the increase in salinity during the first and second fortnight of July and during the first and second fortnight of September by the influence of coastal upwelling phenomenon. But, in the higher saline zone, the surface waters showed an increasing trend from the second fortnight of May to first fortnight of July with decrease in salinity from 31.3 ‰ to 6.7 ‰. Menon et al. (1975) reported a similar increasing trend from July to September when salinity decreased. In the bottom waters, the increasing trend in copepods leading to the peak was noticed during the same period when the salinity was between 33 and 34 ‰ (Figs. 10 & 11). These observations confirm that salinity is not the only factor to limit the copepod population in the estuarine waters during monsoon season. Temperature and dissolved oxygen also did not show any direct relationship with the fluctuation and abundance of copepods in the present investigation. It may be concluded that the biological factors such as food availability, species composition of copepods, their life span and reproductive potential of the different species in space and time might have vital role in limiting the population. This is in view with the findings of George (1958) while it contradicts the observations of Silas and Pillai (1975) who stated that salinity is the main factor that limits copepod population. The copepod population has also been reported to be limited by the occurrence of other zooplankton groups like cladocerans (Menon et al., 1971), ctenophores and hydromedusae (Madhupratap, 1987).

Chaetognaths showed relatively even distribution in the upper water column from surface to mid-depth in the higher saline zone while their density in the bottom layer showed decline during the first fortnight of June and second fortnight of July to distinguish three sets of chaetognath species with reference to salinity distribution (Fig. 11). The unusual increase noticed in the bottom layer during the first and second fortnight of August appears to be related to the incursion of colder offshore water into this region in connection to the coastal 'upwelling' phenomenon as evidenced by the record of relatively low temperature and dissolved oxygen and higher salinity in the bottom waters during the first fortnight of August at station-3 (Fig. 11), so that the offshore species of chaetognaths must have been brought along with the current into this region. This increase in the chaetognath number is reflected to some extent in the surface layer by dispersal during the first and second fortnight of August (Fig. 10). A similar increase has been reported by Menon et al. (1971) and Vijayalakshmi (1971) in September, and the numbers recorded by them were 232 and 252 per m^3 respectively.

The distribution of chaetognaths was very much restricted in number in the backwater zone of the study area (Stations 1 and 2) and their occurrence seems to have relationship with salinity. This is in accordance with the findings of Srinivasan (1971). During the onset and closure of monsoon when the salinity of water was relatively high, the number of chaetognaths per m^3 was more. The remarkable increase in number noticed in the bottom waters at stations 1 and 2 might be related to advection process by the frequent incursion of offshore water into the backwater along with the chaetognaths at intervels in relation to the intensity of the coastal 'upwelling' currents and by the rhythmic tidal flow. Their corresponding increase in the surface layer is attributed to dispersal of organisms in the respective stations or by the circulatory pattern and mixing process in the backwater.

The results revealed that the cladocerans were, in general, very less during May and June at the bottom layer in all stations where the salinity showed wide range from the marine to nearly freshwater condition; while the surface layer contained relatively more number at station-1 and less at station-3 with the maximum (80 nos/m^3) noticed at station-1 during the second fortnight of May in relation to the onset of monsoon. George (1958), Menon et al. (1971) and Pillai and Pillai (1975) have stated that cladocerans are rare or absent during May and June. In the present study, the number declined at station-2 and came down to nil in the higher saline zone (station-3) when the mean salinity for the three stations were 24.5 ‰, 31.5 ‰ and 31.7 ‰ respectively in the upper column showing preference of medium salinity by the individuals indicating that the cladocerans were exclusively constituted by the estuarine species. Somewhat similar report is given by Menon et al. (1971) from Fairway buoy for May-September when the salinity reduced from 33.0 - 11.6 ‰.

The increase in number of cladocerans from the first fortnight of August leading to the peak in the first fortnight of September at stations 1, 2 and 3 amounting to 2468, 1783 and 1035 nos/m^3 at surface and 3333, 2962 and 604 nos/m^3 in the bottom waters respectively is similar to the trend observed by Menon et al. (1971). But, the density of cladocerans recorded by them (20924 and 18042 nos/m^3) in August and September indicated dense swarming of cladocerans during these months. George (1958) and Silas and Pillai (1975) have noticed a similar increasing trend during August-September as in the present case. But, Pillai and Pillai (1975) have stated that the swarming of cladocerans occurs suddenly without showing any increasing trend. In the present investigation, their abundance at stations 1 and 2 than at station-3 indicates that the cladoceran population was constituted by more of backwater and estuarine species during August-September.

The distribution of cladocerans during June-July in the surface waters in relation to salinity indicated that station-1 was dominated by freshwater species and station-3 by the estuarine species. The reduction in the cladoceran number at station-2 during June-July suggests high rate of mortality of freshwater and estuarine species around this station by the influence of tide and freshwater flow respectively.

Lucifers were present in all the fortnightly samples of surface and bottom layers during the south-west monsoon period in varying concentrations with their maximum recorded in the second fortnight of May during the onset of monsoon, while the observations of George (1958) and Madhupratap and Haridas (1975) showed that Lucifer was absent from July onwards during the south-west monsoon season. During June-September, their unusual abundance at intervels during the second fortnight of June, second fortnight of July, second fortnight of August and first fortnight of September in the surface and bottom waters at station-3 in the higher saline zone (Figs. 10 & 11) and during the second fortnight of July and first fortnight of September at stations 1 & 2 in the backwater (Figs. 6-9) might be attributed to the effects of advection and dispersal processes in relation to the intensity of incursion of high saline offshore water into the backwater.

The distribution and percentage abundance of medusae among the three stations revealed their affinity to saline condition in the estuarine waters of the study area by their abundance in number during the beginning and closure of monsoon when the salinity was relatively high. This is in confirmity with the observations of George (1958), Santhakumari and Vannucci (1971) and Madhupratap and Haridas (1975). Their occurrence was relatively more in the upper water column from the surface to mid-depth in higher saline zone as evidenced from the results at station-3 (Figs. 10 & 11). Their occurrence in the surface layer during peak monsoon months (June-August) at station-3 and gradual reduction at surface and absence at bottom from station-2 to station-1 indicate the mortality of this group by the influence of flood flow.

The results revealed that the decapod larvae were generally abundant from the first fortnight of May to the first fortnight of June especially at station-1. From the record of dense swarm of the brachyuran larvae in the lesser saline zone (station-1) on 1-6-1991 to the extent of 50573 nos/m^3 in the water column, it appears that the initial monsoon rainfall occurred in May resulting in sudden change in salinity and other water characteristics might have triggered the spawning of brachyuran decapod in the backwater environment. The abundance of decapod larvae in such high numbers at station-1 during the first fortnight of June and the considerable reduction in number without swarm noticed at stations2 and 3 simultaneously and the absence of their abundance in the next fortnight in the study area (absent even in the next weekly observation) suggest heavy mortality of these larvae as the result of heavy downpour of rainfall leading to almost freshwater condition and changes in other environmental factors. Menon _et al_. (1971) reported an increasing trend from May-July with peak in July, while George (1958) and Madhupratap and Haridas (1975) recorded the minimum number in the beginning of June. This might be due to fluctuation in the onset of monsoon in the respective years of investigation. During the rest of the period, the planktonic decapods were less in number in the study area.

The distribution and percentage abundance of fish eggs and larvae showed wider fluctuations between surface and bottom layers and among the stations. The results revealed that their abundance is more related to the habitat of the breeder. This is in accordance with the findings of George (1958). The relatively high number of 96 and 50 nos per m^3 recorded at station-1 during the second fortnight of May and first fortnight of June respectively and the absence of this peak at station-3 suggest that these eggs and larvae may belong to the estuarine species or group only; whereas the abundance of fish eggs and larvae at station-3 in the surface and bottom waters (186 and 276 nos/m^3 respectively) during the second fortnight of August and their occurrence in the bottom waters at stations 1 and 2 in considerable number indicate that they may belong to a demersal species or group and their transport from the sea to the backwater could be due to the influence of coastal upwelling currents and tidal flow as evidenced by the low temperature and dissolved oxygen and high salinity in the second fortnight of August at stations 1 and 2 (Figs. 7, 9 & 11).

The quantitative estimation of zooplankton revealed that the mean number of total zooplankters in the study area was 2381 per m^3 during the south-west monsoon period commencing from May to September and were distributed at 47% and 53% in the surface and bottom waters respectively. The occurrence of relatively more number of zooplankters at station-1 (3497 nos/m^3) than at station-2 (1549 nos/m^3) and station-3 (2098 nos/m^3) for this entire period (Table-5), and their overall abundance during the peak monsoon (40.23%) and close of monsoon (37.07%) than at the onset of monsoon (22.7% in total) confirm that the south-west monsoon has great influence on zooplankton production in back-water environment.

During the south-west monsoon season, the zooplankton was constituted by copepods (367 nos/m^3) followed by cladocerans (227 nos/m^3), lucifers (172 nos/m^3), decapod larvae excluding the swarm (131 nos/m^3), and chaetognaths (84 nos/m^3) in the order of abundance in the study area.

The month-wise percentage composition of the important zooplankton groups in the entire study area (Fig. 24) revealed that the copepods were abundant in May (23.78%), June (11.78%) and July (31.39%); chaetognaths in August (14.24%); cladocerans in August (13.15%) and September (44.81%); lucifers in May (32.93%) and decapod larvae in June (78.98%) when the total number of zooplankters per m^3 were 1497, 3717, 3256, 992 and 2444 for May, June, July, August and September respectively.

The season-wise distribution of the different groups revealed that chaetognaths, lucifers and medusae were higher in percentage at the onset of monsoon while cladocerans reached their maximum in the postmonsoon month (September). During the peak monsoon months (June-August), copepods and cladocerans exhibited wide fluctuations in their distribution and abundance by the influence of their freshwater species from the upstream waters along with freshwater flow; while the chaetognaths, lucifers and fish eggs and larvae showed wider fluctuations in the study area due to the occasional/discontinuous incursion of high saline sea water into the backwater depending on the intensity of coastal upwelling currents; and the wide fluctuation observed in the pelagic decapods was due to the swarming of brachyuran zoea.

The results of statistical analysis for the influence of hydrographic parameters like rainfall, temperature, salinity and dissolved oxygen on zooplankton fluctuation and abundance showed that salinity alone had significant influence, indicated by the high correlation coefficient('r') obtained for total zooplankton, lucifer and decapod larvae. Though the 'r' values for the other groups were significant, they showed less than 0.5; and this could be attributed to the interference of freshwater and estuarine species of the respective groups during this season.

Although the rainfall in the south-west monsoon season appeared to have, in general, no significant correlation with the zooplankton fluctuation and abundance, the consequent freshwater discharge in the estuarine ecosystem resulting in the reduction in salinity showed influence in the present investigation. Apart from these, biological factors such as food availability, species composition, life-span and reproductive potential of the species concerned may have significant role in the fluctuation and abundance of zooplankton density. Keeping these in view, ecological investigations at the species level are desirable in the study of correlation between the zooplankton fluctuation and the environmental factors to come to any definite conclusion.

S U M M A R Y

This dissertation presents the results of investigation carried out on the fluctuation and abundance of zooplankton in relation to the environmental parameters in the Ernakulam channel of the Cochin backwater between the road-cum-railway bridge and Fairway buoy during the south-west monsoon months from May to September 1991.

The importance of zooplankton production, resume of literature and scope of the study are mentioned under the title 'Introduction'. The description of the study area and methodology in the collection and analysis of samples and treatment of data are included in 'Material and methods'.

The findings and conclusions derived from the present study were based on the weekly data obtained on the monsoon-related hydrographic parameters such as rainfall, water temperature, salinity and dissolved oxygen and the total zooplankton and dominant groups, from the surface and bottom layers at the three fixed stations from the lesser saline zone, middle zone and higher saline zone respectively.

Considering both the numerical abundance and frequency of occurrence in the samples during June-September, zooplankton groups like copepods, chaetognaths, cladocerans, lucifers, medusae, decapod larvae and fish eggs and larvae were treated as individual groups, while the groups constituting less than 0.5%

in the mean total (number/m^3) for June-September (excluding the blooms/swarms in the samples) were treated under 'others' which included appendicularians, ctenophores, dinoflagellates, doliolids, isopods, ostracods, planktonic polychaetes and siphonophores.

Since the measurements were subjected to diurnal, micro-distributional and experimental sources of variability, individual values of these parameters were not considered (as far as possible) and the data were consolidated to fortnightly, monthly and seasonal (onset, peak and closure of monsoon) averages for the results and discussion.

The Cochin region had the local rainfall of 2600 mm during the south-west monsoon season constituting more than 80% of the annual mean (3230 mm). The rainfall at the onset (May), peak (June-August) and closure (September) of monsoon registered 80, 2466 and 54 mm respectively. The monthly rainfall showed the maximum (1492 mm) in June during May-September.

Water temperature, salinity and dissolved oxygen showed vertical gradients with higher values of temperature and dissolved oxygen and lower values of salinity at the surface layer during peak monsoon months, indicating the influence of freshwater flow.

The results indicated that the bottom waters at stations 1 and 2 occasionally registered unusually low values of temperature and dissolved oxygen and high salinity values during June-

September indicating the incursion of high saline offshore waters into the backwater during south-west monsoon season.

From the bihourly diurnal data obtained for the months of June and July, it was confirmed that this incursion was not due to the influence of high tide but due to the coastal 'upwelling' currents moving towards the coast along the bottom elevated topography without affecting the surface layer much.

The record of such unusually high saline waters at intervals confirmed that this phenomenon was not a continuous process and the intensity of this current varied from time to time. The fortnightly results revealed that the frequency of this occurrence reduced from the higher saline zone (station-3) to the lower saline zone (station-1) indicating the intensity of incursion by the coastal 'upwelling' currents.

During the south-west monsoon season, dense swarming of decapod larvae (brachyuran zoea) to the extent of 50573 nos/m^3 was recorded in the lesser saline zone during the first week of June when the mean salinity was 17.67 ‰ in the water column.

Another bloom/swarm of dinoflagellates (<u>Noctiluca</u>) to the extent of 13653 nos/m^3 was recorded at station-1 during the third week of July when the mean salinity was 16.17 ‰ in the water column; and their abundance reduced at the other two stations.

Apart from these, abundance of cladocerans (2900 nos/m^3) at station-1 and pelagic polychaetes (653 nos/m^3) at station-2 were recorded during the first week of September. They were relatively more in the bottom waters.

The quantitative estimation revealed that the mean number of total zooplankton in the entire study area for the south-west monsoon season was 2381 per m^3 and were distributed in the surface and bottom layers at 47% and 53% respectively.

The fortnightly distribution of total zooplankton indicated that the fluctuation was considerably more at stations 1 and 2 (backwater stations) than at station-3 (higher saline zone).

Their abundance in the lesser saline zone (station-1) during the peak and closure of monsoon than at the onset of monsoon confirmed that the south-west monsoon had more influence on zooplankton production in the backwater environment.

The relatively low density of zooplankton observed at station-2 than at stations 1 and 3 during the peak monsoon months might be due to high rate of mortality of the freshwater species from the upstream and estuarine species from the sea by the influence of tidal flow and flood flow respectively at this middle zone.

During this season, excluding the swarms, the dominant groups that constituted the bulk of the zooplankton in the study area were copepods (367 nos/m^3) followed by cladocerans (227 nos/m^3), lucifers (172 nos/m^3), decapod larvae (131 nos/m^3) and chaetognaths (84 nos/m^3) in the order of abundance.

The mean values of copepods for the onset, peak and closure of south-west monsoon were estimated as 350, 446 and 148 nos/m^3 respectively in the entire water column of the study area. The results revealed that the fluctuation in copepod abundance was relatively more in the bottom waters.

The mean values of chaetognaths for the onset, peak and closure of monsoon were estimated as 96, 92 and 50 nos/m^3 respectively in the entire water column of the study area. The results indicated that the fluctuation in chaetognath abundance was more at station-1.

The mean values of cladocerans for the three sub-seasons (onset, peak and closure) were estimated as 17, 52 and 965 nos/m^3 respectively for the whole study area. The results revealed that the fluctuation in cladoceran abundance was relatively high in the higher saline zone.

The mean values of lucifer for the onset, peak and closure of monsoon were estimated as 494, 95 and 81 nos/m^3 respectively for the entire water column. The results indicated that fluctuation in the abundance of lucifers was generally high in the bottom waters.

The mean values of medusae for the three sub-seasons were estimated as 61, 7 and 26 nos/m^3 respectively in the whole study area. The results indicated that the fluctuation in the abundance of medusae was maximum in the lesser saline zone and minimum in the higher saline zone (station-3).

The mean values of decapod larvae for the onset, peak and closure of monsoon were estimated as 353, 1012 and 66 nos/m^3 respectively in the entire water column of the study area. The increase in value during peak monsoon was due to the swarm observed on 1-6-1991. The results revealed that fluctuation in decapod abundance was very high at station-1 when compared to the other two stations (due to the swarming).

Mean values of fish eggs and larvae for the three sub-seasons within the south-west monsoon were 28, 27 and 7 nos/m^3 respectively for the entire water column. The results revealed that the fluctuation in the abundance of fish eggs and larvae (together) was very high at stations 1 and 3.

Mean values of 'others', for the onset, peak and closure of south-west monsoon were 101, 923 and 1049 respectively for the entire water column of the study area.

The relative abundance among the different zooplankton groups revealed that lucifers contributed the maximum (494 nos/m^3) followed by decapod larvae, copepods, chaetognaths, medusae, fish eggs and larvae and cladocerans respectively during the onset of monsoon (May).

During peak monsoon period (June-August), excluding the high number recorded for the decapod larvae due to the dense swarm observed on 1-6-1991, copepod contributed the maximum (446 nos/m^3) followed by lucifers, chaetognaths, cladocerans, fish eggs and larvae and medusae respectively.

During the closure of the monsoon (September), cladocerans contributed the maximum (965 nos/m^3) followed by copepods, lucifers, decapod larvae, chaetognaths, medusae and fish eggs and larvae respectively.

Succession of species was indicated in the case of copepods by the presence of three modes especially in the surface waters during the onset, peak and closure of monsoon respectively and it was prominant in the backwater stations. This trend was reflected in the total zooplankton distribution also.

Studies on the influence of rainfall revealed that the regional rainfall was not directly responsible for the abundance of zooplankton in the estuarine waters during the south-west monsoon season. The consequent freshwater flow was found to reduce the total zooplankton, as seen from the relatively less number at the surface waters during south-west monsoon season.

The tidal flow was found to increase the zooplankters in the bottom waters as evidenced from the high values recorded at high tide.

The influence of coastal 'upwelling' currents were found to increase the zooplankton number at intervals, especially in the bottom waters depending on the intensity of the currents. The influence of these currents could be seen from the unusual high values recorded at intervels for chaetognaths, lucifers and fish eggs and larvae during June-September.

The observed monthly mean values indicated that the percentage of lucifers and medusae was high when the salinity was 28-29 ‰ and copepods, chaetognaths and fish eggs and larvae were higher when salinity ranged between 14 and 17 ‰. Temperature and dissolved oxygen did not seem to have much influence on the zooplankton fluctuation and abundance in the estuarine waters during the south-west monsoon season.

The statistical treatment of the data revealed that salinity alone had significant influence on zooplankton fluctuation and abundance as indicated by the high correlation co-efficient ('r') for the total zooplankton and among the groups for lucifers and decapod larvae.

However, detailed ecological investigations at the species level are desirable in the study of correlation between the organisms and the environmental factors to come to any definite conclusion.

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